Special Waste Residue Management for Alberta

RMD Report 84/27

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SPECIAL WASTE

RESIDUE MANAGEMENT FOR ALBERTA

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This report has received external peer review.

This report may be cited as:

Hrudey, Steve E. 1984. Special waste residue management for Alberta. Prep. for Alberta Environment, Research Management Division by the Department of Civil Engineering, University of Alberta. Edmonton, Alberta: Research Management Division. RMD Report 84/27. 172 pp.

SPECIAL WASTE
RESIDUE MANAGEMENT FOR ALBERTA

by

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for

RESEARCH MANAGEMENT DIVISION
Alberta Environment

RMD Report 84/27

March 1983

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TABLE OF CONTENTS

Page

LIST OF TABLES... viii

LIST OF FIGURES.. x

ABSTRACT... xi

ACKNOWLEDGEMENTS... xii

1. INTRODUCTION.. 1
1.1 Background... 1
1.2 Statement of Need.................................... 1
1.3 Definition of Residues............................... 1
1.4 Information Sources.................................. 2

2. WASTE INVENTORY....................................... 3

3. TECHNOLOGY.. 9
3.1 Literature... 9
3.2 Current Practice..................................... 9
3.3 Technology Considerations for Alberta................ 15

4. RESIDUE GENERATION.................................... 18
4.1 Physical/Chemical Treatment.......................... 18
4.1.1 Neutralization..................................... 18
4.1.2 Oxidation.. 19
4.1.3 Reduction.. 23
4.1.4 Precipitation...................................... 25
4.1.5 Oil/Water Separation............................... 26
4.1.6 Solvent/Fuels Recovery............................. 27
4.1.7 Adsorption... 28
4.1.8 Summary for Mixed Physical/Chemical Wastes......... 28
4.2 Biological Treatment................................. 29
4.2.1 Activated Sludge................................... 29
4.3 Incineration... 31
4.3.1 Rotary Kiln Incinerators........................... 32
4.3.1.1 Bottom Ash Residues.............................. 35
4.3.1.2 Flyash... 37
4.3.1.3 Scrubber Sludge.................................. 42
4.3.2 Liquid Injection Incinerators...................... 43

5. RESIDUE PROCESSING.................................... 46
5.1 Dewatering... 46
5.2 Stabilization.. 48
5.2.1 Cement Based Processes............................. 49
5.2.2 Pozzolanic Processes............................... 51
5.2.3 Thermoplastic Processes............................ 53

TABLE OF CONTENTS (CONTINUED)

Page

6. RESIDUE DISPOSAL 55
6.1 Disposal Concerns 55
6.1.1 Landfill Disposal 55
6.1.1.1 Operational Phase Concerns 55
6.1.1.2 Long-term Concerns 56
6.1.2 Land Treatment 60
6.1.3 Deep Well Injection 61
6.1.3.1 General Groundwater Degradation 62
6.1.3.2 Toxic Waste Disposal 63
6.2 Technical Factors 64
6.2.1 Landfill 64
6.2.1.1 Leachate Migration 64
6.2.1.2 Control Leachate Generation 68
6.2.1.3 Leachate Drainage and Collection 69
6.2.1.4 Cell Liner 69
6.2.1.5 Site Assimilation Capacity 71
6.2.1.6 Gas Generation and Colletion 72
6.2.2 Land Treatment 72
6.2.3 Deep Well Injection 74
6.3 Regulatory Considerations 76
6.3.1 Landfill 80
6.3.2 Land Treatment 81
6.3.3 Deep Well Injection 81

7. COSTS 85

8. CONCLUSIONS 92
8.1 Criteria for Residue Management 92
8.2 Research Needs 95

9. REFERENCES CITED 97

10. APPENDICES 104
10.1 North American and Europen Site Visit Information and Contacts 104
10.2 University of California at Davis (UCD) Waste Classification System 120
10.3 Aggregation of Alberta Waste Categories According to Modified Ontario Categories Based upon the UCD Code System 131
10.4 RCRA Part 264 Hazardous Waste Landfill Regulations (Excerpt) 137
10.5 RCRA Part 264 Hazardous Waste Groundwater Quality Monitoring Regulations (Excerpt) 143

continued ...

TABLE OF CONTENTS (CONCLUDED)

Page

10.6 RCRA Part 264 Hazardous Waste Land Treatment Regulations (Excerpt) 152
10.7 RCRA Part 264 Hazardous Waste Regulations Preamble (Excerpt) 166

LIST OF TABLES

Page

1. Estimated Quantities of Hazardous Waste Generated in Alberta ... 4

2. Hazardous Waste Generation by Industrial Sector 7

3. Estimated Bottom Ash Residue Generation Rate for Rotary Kiln Incinerator Facilities 36

4. Rotary Kiln Bottom Ash Residue Analysis for Trace Organics 38

5. Analysis of Solid Residues from PCB Test Burns 39

6. Inorganic Composition of Bottom Ash Residues from Rotary Kiln Incinerators 40

7. Inorganic Composition of Flyash Residues from a Rotary Kiln Incinerator 41

8. Composition of Ash Residues from a Liquid Injection Incinerator 45

9. Characteristics of Common Dewatering Devices 47

10. Average Leachate Characteristics: GSB Gallenbach Secure Landfill 58

11. Leachate Characteristics: ZVSMM Schwabach Secure Landfill 59

12. Characteristics of Industrial Wastes and Factors Affecting Their Safe and Effective Detoxification, Degradation, and Inactivation in Land Treatment Systems 73

13. Proposed Cumulative Soil Loading Limits for Selected Metals 75

14. Cost Comparisons among Hazardous Waste Treatment and Disposal Technologies 86

15. Treatment and Disposal Fees at European Facilities 87

16. Treatment and Disposal Fees at North American Facilities 88

17. Annual Revenue Per Unit Required to Offset Incremental Costs Due to RCRA Part 264 Regulations: Landfill by Unit Size 89

18. Annual Revenue Per Unit Required to Offset Incremental Costs Due to RCRA Part 264 Regulations: Land Treatment by Unit Size . 91

continued ...

LIST OF TABLES (CONCLUDED)

Page

19. North American and European Site Visit Information and Contacts 105

20. University of California at Davis (UCD) Waste Classification System 121

21. Aggregation of Alberta Waste Categories According to Modified Ontario Categories Based on UCD Code System 132

LIST OF FIGURES

Page

1. Proportional Distribution of Wastes in Major Categories 6
2. Hazardous Waste Treatment Technology Found at European and North American Facilities 11
3. Proportion of Plants and Proportion of Wastes According to Technology for North American Facilities 13
4. Proportion of Plants and Proportion of Wastes According to Technology for European Facilities 14
5. Process Schematic for Neutralization 20
6. Process Schematic for Alkaline Chlorination 22
7. Process Schematic for Chromate Reduction 24
8. Process Schematic for Rotary Kiln Incineration 33
9. Definition Sketch for Darcy's Law 65
10. Practical Range for Hydraulic Conductivity 67
11. Monitoring Scheme for Idealized Deep Well Disposal System 77

ABSTRACT

In support of an overall program to establish a centralized facility for the management of hazardous wastes in Alberta, the problem of residues requiring ultimate disposal was investigated. Current hazardous waste treatment was evaluated, for exemplary facilities, by conducting site visits to 44 operating plants in Europe and North America and by reviewing published site visit reports for five other European facilities. The conventional literature, government, and industry publications were also reviewed.

Existing hazardous waste inventory estimates for Alberta were compared to inventory data from Ontario and California and were found to be relatively consistent. The technology in use at operating facilities was found to be considerably less diverse than would be anticipated from reviewing the literature alone. In total, only 12 major classes of technology were observed. Overall, European plants tended to be centralized with a common battery of treatment technology including: incineration, neutralization, oxidation, reduction, oil separation, precipitation, and filtration. North American facilities were generally more specialized in their capabilities.

Landfill was found to be a receptor for a major portion of the total waste tonnage handled at both European and North American plants. This finding suggests that the importance of the residue landfill for the Alberta facility should not be underestimated. However, a relatively small land area would be required for the Alberta landfill.

Residue characteristics and quantities were documented for the treatment processes currently in commercial use. Although quantities of treatment residues are significant, residue processing and stabilization can provide effective management for these materials. Final residue disposal options by landfill, land treatment, and deep well were evaluated for their potential environmental impact. Management approaches for these disposal options are presented.

Finally, research needs emerging from this review of hazardous waste residue management are presented. These indicate a need for ongoing research activity at the operating facility.

ACKNOWLEDGEMENTS

This research was funded by a grant-in-aid of research (RMD 81-08) from the Research Management Division of Alberta Environment. The project was conducted in consultation with Mr. Ken Simpson, Head, Waste Management Branch, Pollution Control Division, and Dr. Brian Hammond, Senior Research Scientist, Research Management Division. Site investigations were conducted during a study leave provided by the University of Alberta.

The excellent co-operation of plant personnel and management at the many facilities visited was instrumental in providing an extensive information upon which this report is based.

1. INTRODUCTION

1.1 BACKGROUND

In September 1979 Alberta Environment Minister Jack Cookson named a hazardous waste management committee to look into disposal of special wastes in Alberta and propose recommendations for government action. This committee reported in January 1980 and recommended that an integrated waste treatment system consisting of the best available technology, as demonstrated in Europe, should be established in Alberta to manage industrial and other special wastes being generated. Several studies have been done to identify components such as available technologies, estimated waste quantities, and economic factors. Subsequently, a request for proposals to construct and operate an integrated waste management facility was issued in December 1981 and Chem-Security Ltd. was selected as prime contractor in the spring of 1982.

Accordingly, planning for the construction and operation of an integrated hazardous waste management facility has been proceeding.

1.2 STATEMENT OF NEED

Given the progress towards construction of an integrated facility, detailed design criteria for such a system become necessary. As well, facility siting activities require that an accurate projection of proposed developments be provided.

Of major concern to the foregoing are the disposal requirements of the ultimate residues generated by technologies likely to be employed by the integrated plant. A brief review of available information in the spring of 1981 indicated a need for more specific information on this subject, particularly as applicable to Alberta.

1.3 DEFINITION OF RESIDUES

For the purposes of this report, residue refers to any solid or liquid by-product or material resulting from hazardous wastes or hazardous waste treatment processes which cannot be substantially altered by further treatment and must be disposed to an ultimate receptor.

1.4 INFORMATION SOURCES

Evaluation of residue disposal requirements was undertaken based on information provided from:

1. the conventional literature (books and journal articles);
2. government reports and documents;
3. industry-generated trade literature;
4. site visit reports, prepared by others, respecting five operating hazardous waste facilities in Europe; and
5. site visits and personal interviews at 44 operating hazardous waste facilities in Europe and North America.

The last category provided a thorough appreciation of the scope and reality of hazardous waste treatment and disposal. Without this phase, it is unlikely that a practical evaluation of the other information sources would have been possible. Summary details of the sites visited and appropriate contacts are provided in Appendix 10.1.

2. WASTE INVENTORY

Performing an independent inventory of expected hazardous waste quantities and types was beyond the scope of this study. Yet, this type of information was clearly necessary to orient any discussion on ultimate residue disposal for an integrated Alberta plant. Reid, Crowther & Partners Ltd. (1980) conducted an inventory to estimate the likely quantities and types of hazardous wastes being generated in Alberta. This inventory was done largely on the basis of predictions of waste generation per production employee. Since this study provided the only specific estimates of waste quantities for Alberta, these estimates were evaluated for their consistency with detailed studies done elsewhere. Table 1 summarizes the projected quantities of hazardous waste according to the Reid Crowther inventory.

Although many hazardous waste inventories have been conducted by various disciplines, it is extremely difficult to obtain reliable or meaningful data. The problems encountered include: lack of awareness of actual waste generation on the part of industry; unwillingness on the part of some industries to admit that hazardous wastes are generated; discrepancies between estimated waste quantities generated and actual waste quantities that would be shipped when a price is charged; strong interaction between willingness to ship wastes for treatment and regulatory requirements; and inadequate detail about types and characteristics of wastes to allow facility planning.

Comparison of inventories done by different jurisdictions is also difficult because each investigation has adopted its own approach to categorizing wastes. The only common thread among several recent inventory studies was the University of California at Davis (UCD) waste classification scheme. This system (summarized in Appendix 10.2) was developed on a contract to the California Office of Appropriate Technology (Toxic Waste Assessment Group 1981). It provides 106 specific waste categories developed from consideration of major industrial processes and information from the California Department of Health Services (DHS) hazardous waste manifest

Table 1. Estimated quantities of hazardous waste generated in Alberta.[a]

Waste Type	Quantity t/a
PCB	10
Oils	20 000
Solvents (Halogenated)	900
Solvents (Non-halogenated)	5 600
Heavy Metal Solvents	negligible
General Mixed Metal Bearing Sludge	5 000
Lead Sludge	negligible
Chromium	100
Copper	negligible
Aluminum	70
Magnesium	0
Pesticides	180
Textile Waste Treatment	10
Ink	10
Organic Tannery Waste	2 100
Dust and Scrubber	90
Paint	300
General Mixed Aqueous (Water) Metal Bearing Sludge	50
Acids with Heavy Metals	500
Acids	23 700
Alkalis with Heavy Metals	70
Alkalis	5 500
Plastic, Resins, and Latex	460
Phenols	60
Cyanides	1 200
Phosphate Sludge	10
Explosives	negligible
Contaminated Containers and Equipment	460
Contaminated Soil and Sand	2 500
Asbestos	3 700
Ammonia	10
Scrap Batteries	10
Waste Activated Carbon	40
Infectious Waste	1 200
Tank Bottoms	1 300
Chemicals	12 200
Sulphur	200
Fly Ash	150
Photo Chemicals	1 100
Spent Catalyst	negligible

[a] Source: Reid Crowther (1980)

system. The UCD system was adopted by the Ontario Waste Management Corporation inventory (Proctor and Redfern 1982). They reaggregated data classified by this scheme into 14 major categories to provide a manageable breakdown for data handling purposes. For the present study, these groups were further aggregated to 12, making them potentially compatible with the Alberta categories (Appendix 10.3) used in the Reid Crowther (1980) report. Although the UCD system differed from the 40 categories specified in the Alberta inventory, it was possible, given the detail of the UCD system, to assign UCD categories to the Alberta data. These could then be reaggregated into 12 categories according to the Ontario approach, thereby allowing comparison.

Two other data bases were also obtained for comparison. One was based upon study of the California DHS manifests for two distinct two-month periods which were extrapolated to one year (Toxic Waste Assessment Group 1981). The other was based on actual manifested receipts for 1981 at California's largest hazardous waste (Class I) landfill (BKK site visit, 1982). These data were also processed according to the Ontario inventory approach and the resulting data are plotted in Figure 1 as per cent total annual waste in the 12 specified categories. The similarity in distribution of wastes into these categories for three different jurisdictions and four data sources is somewhat remarkable. Data from BKK is particularly interesting since this represents actual waste receipts at California's largest hazardous waste landfill.

Finally, a comparison of hazardous waste generation between Alberta, Ontario, and California was attempted on the basis of standard industrial classification (SIC) codes. Table 2 summarizes this comparison. Although waste load generation by SIC code category was provided for Ontario (Proctor and Redfern 1982) and California (Toxic Waste Assessment Group 1981), only data on production employee per SIC code was provided by Reid Crowther (1980). This fact limits the comparison but it appears that Alberta may have an industrial profile closer to California than to Ontario.

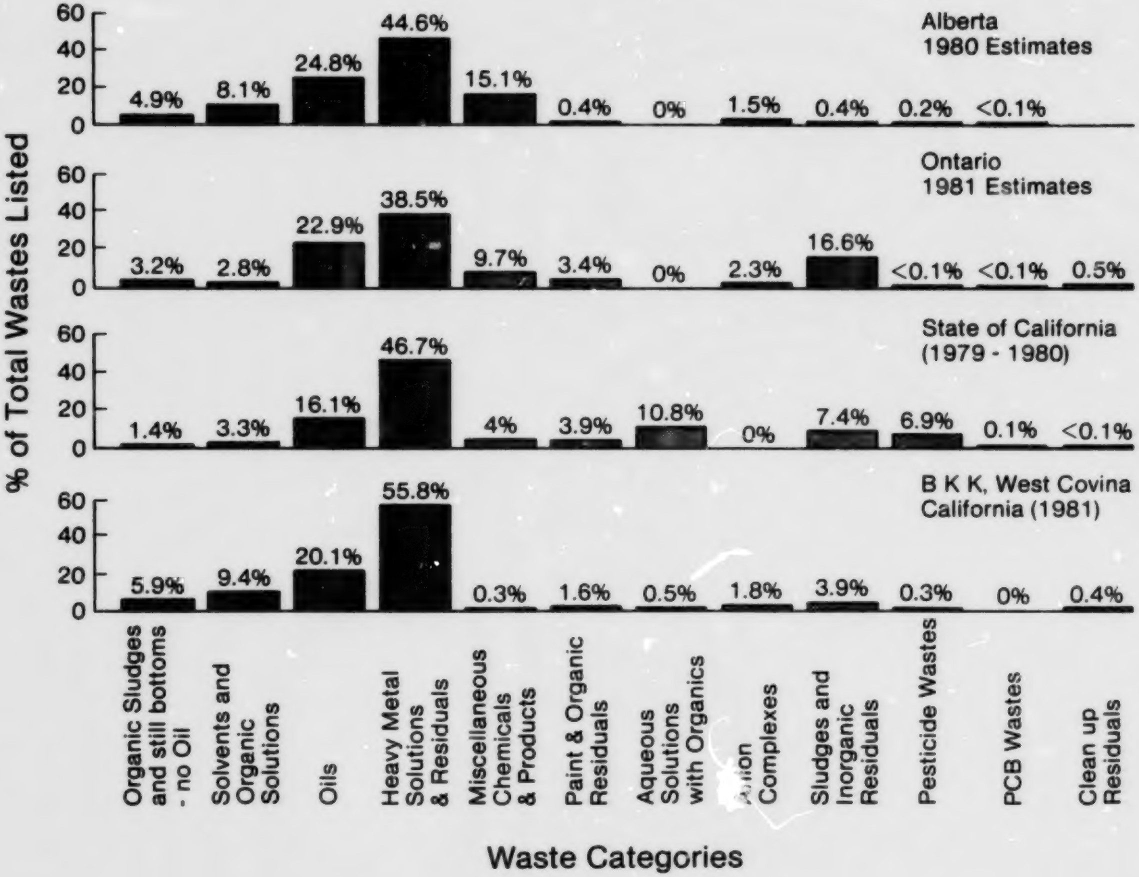


Figure 1. Proportional distribution of wastes in major categories.

Table 2. Hazardous waste generation by industrial sector.

Major SIC Code	Alberta[b]		Ontario[c]		California[d]	
	Production Employees per Industry	% of Total Production Employees	Waste Generation t/a	% of Total Waste Generation	Waste Generation t/a	% of Total Waste Generation
13 Crude Oil & Natural Gas Production	10 547	29.5	N.R.[a]	0	265 164	9.5
16 Construction (other than building)	N.R.[a]	0	8 900	0.6	N.R.[a]	-
20 Food & Kindred Products	N.R.[a]	0	7 700	0.5	4 890	<0.1
22 Textile Mill Products	303	0.8	1 400	0.1	N.R.[a]	-
23 Apparel	N.R.[a]	0	400	0.1	N.R.[a]	-
24 Lumber & Wood Products	N.R.[a]	0	1 400	0.1	990	<0.1
25 Furniture & Fixtures	N.R.[a]	0	6 200	0.4	N.R.[a]	-
26 Paper Products	2 230	6.2	82 700	5.5	10 242	0.8
27 Printing/Publishing	N.R.[a]	0	20 500	1.4	1 824	0.1
28 Chemicals	3 577	10.0	146 900	9.9	265 848	19.6
29 Petroleum	1 245	3.5	62 800	4.2	381 342	28.0
30 Rubber & Plastics	566	1.6	12 700	0.9	1 146	0.1

continued ...

Table 2. Concluded.

Major SIC Code	Alberta[b] Production Employees per Industry	Alberta[b] % of Total Production Employees	Ontario[c] Waste Generation t/a	Ontario[c] % of Total Waste Generation	California[d] Waste Generation t/a	California[d] % of Total Waste Generation
31 Leather Products	97	0.3	3 000	0.2	11 694	0.9
32 Stone, Clay, Glass, & Concrete Products	4	0	19 500	1.3	27 750	1.6
33 Primary Metal Industries	3 159	8.8	766 700	51.5	26 802	2.0
34 Fabricated Metal Products	5 707	15.9	125 200	8.4	64 266	4.7
35 Machinery (except electrical)	4 237	11.8	106 200	7.1	181 360	1.4
36 Electrical Machinery	810	2.3	16 200	1.1	55 500	4.1
37 Transportation Equipment	1 744	4.9	82 600	5.5	47 592	3.5
38 Measuring, Analysing, & Controlling Instruments	N.R.[a]	0	5 200	0.3	7 740	0.6
39 Miscellaneous Manufacturing Industries	N.R.[a]	0	7 800	0.5	N.R.[a]	-
72 Personal Services	1 097	3.1	N.R.[a]	0	N.R.[a]	-
73 Business Services	398	1.1	N.R.[a]	0	4 956	0.4
75 Automobile Repair (paint shops)	72	0.2	N.R.[a]	0	1 842	0.1

[a] Not reported

[b] Source: Reid Crowther 1980

[c] Source: Procter and Redfern 1982a

[d] Source: Toxic Waste Assessment Group 1981

3. TECHNOLOGY

3.1 LITERATURE

Suitable technology for the treatment and disposal of hazardous wastes has come under increasing scrutiny in recent years. An extensive review (A.D. Little 1976) compiled details on 47 unit processes applicable to hazardous waste treatment. This documentation includes process descriptions, operating characteristics, equipment and material requirements, current applications and cost information, along with conclusions and recommendations for each process. More recently, Kiang and Metry (1982) have reproduced much of this information, together with an expanded coverage of thermal processing of hazardous wastes. The extensive variety of potential technologies is of interest. However, the uncertainty surrounding characteristics of actual hazardous waste in Alberta precludes serious consideration of technologies which are not already being successfully applied elsewhere. Pioneering a "new technology" without having confirmed details of the waste profile would be unwise.

3.2 CURRENT PRACTICE

Based on the foregoing premise, technologies actually in use at operating facilities were compiled. Facilities reviewed included both those which were visited and those for which detailed site visit reports could be located. Following a review of published facility inventories, contacts were made with provincial, federal, and U.S. Environmental Protection Agency officials. Facilities to be reviewed were selected on the basis of sophistication of technology, operating reputation, and significant size.

The review of facilities identified 12 major categories of process technology, namely:

1. incineration;
2. fuels recovery;
3. solvent recovery;

4. neutralization;
5. oxidation;
6. reduction;
7. oil separation;
8. precipitation;
9. complexation;
10. adsorption;
11. filtration; and
12. biological processes.

Because of the selection process for plants which were surveyed, the following data analysis cannot be generalized to all plants and wastes in the respective jurisdictions. However, the data do tend to reflect practice at those plants generally regarded as effective in their respective jurisdictions.

Figure 2 illustrates the prevalence of the foregoing technologies at plants surveyed in Europe and in North America. The European plants selected were biased to those with treatment, particularly incineration. Given the limited time and high costs associated with site visits, no sites with only landfills were surveyed in Europe. Of the 11 sites reviewed, 10 had employed treatment and one employed deep mine storage. In North America, 23 of the 32 commerical offsite facilities performed some treatment, while the remainder were strictly landfills.

This summary suggests an important distinction between North American and European hazardous waste treatment practice. In Europe, several centralized facilities exist which employ a relatively consistent set of processes. In fact, 80% of the facilities surveyed have incineration, neutralization, oxidation, reduction, oil separation, precipitation, and filtration (dewatering) in common. In North America, centralized facilities employing a full range of technologies are uncommon, whereas individual facilities specialized to local markets are more common. This distinction has been interpreted by many officials in North America to suggest a higher degree of sophistication for European hazardous waste management technology. Based upon personal

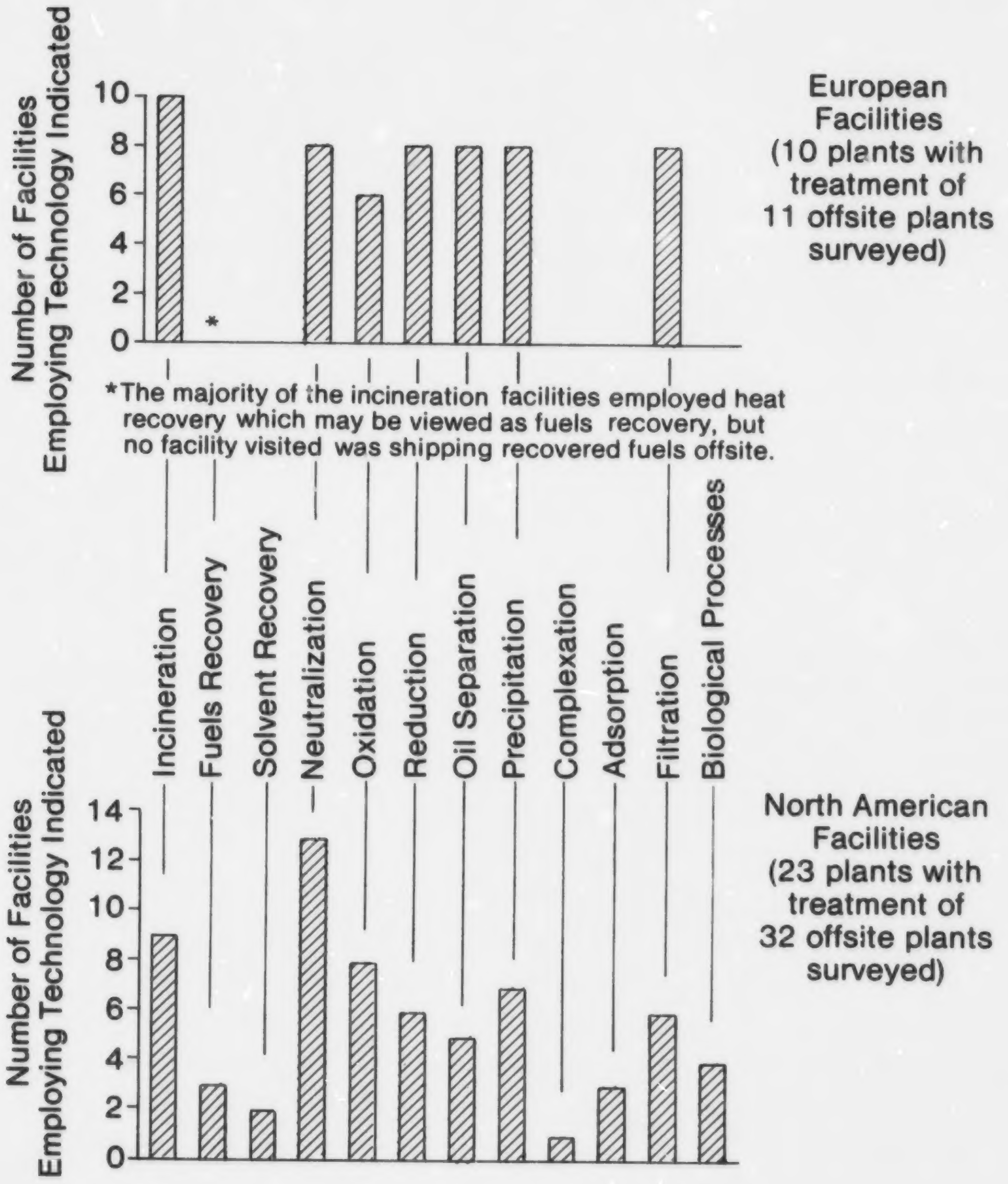


Figure 2. Hazardous waste treatment technology found at European and North American facilities.

observations, that interpretation is not justified. Although newer centralized facilities in Europe have generally maintained a better external appearance than many commercial facilities in North America, the basic technology being employed is not substantially different on either side of the Atlantic.

Another interpretation frequently expressed in North America is that landfill is much more widely used in North America than in Europe. Wider usage would be anticipated strictly on the basis of land availability. To investigate the relative extent of landfill preference in North America an assessment of the comparative importance of landfill was performed. Treatment was grouped into three major categories: incineration; physical/chemical treatment; and biological treatment. The physical/chemical category included: fuels recovery, solvent recovery, neutralization, oxidation, reduction, oil separation, precipitation, complexation, adsorption, and filtration. Disposal practices were grouped into: landfill (on- or offsite), land treatment, and deep well (on- or offsite). For European facilities, landfills were distinguished as either owned by the same organization or owned by others. As well, a category for deep mine storage was added.

Interpretation of this analysis must be based upon the reality that the plants surveyed represent only a large sampling of major operating facilities in Europe and North America. Since plants were selected primarily on the basis of recommendation as worthwhile facilities, both European and North American plants are biased toward the better type of facility. Because the purpose of the assessment was not to assess current waste management, good or bad, but rather to predict residue generation given good waste management practices for Alberta, the bias is appropriate.

Figure 3 summarizes the foregoing categorization for North American facilities while Figure 4 summarizes this categorization for European facilities. Some interesting comparisons are apparent. Figure 3 shows that although one third of North American facilities employ incineration, this technology accounts for only

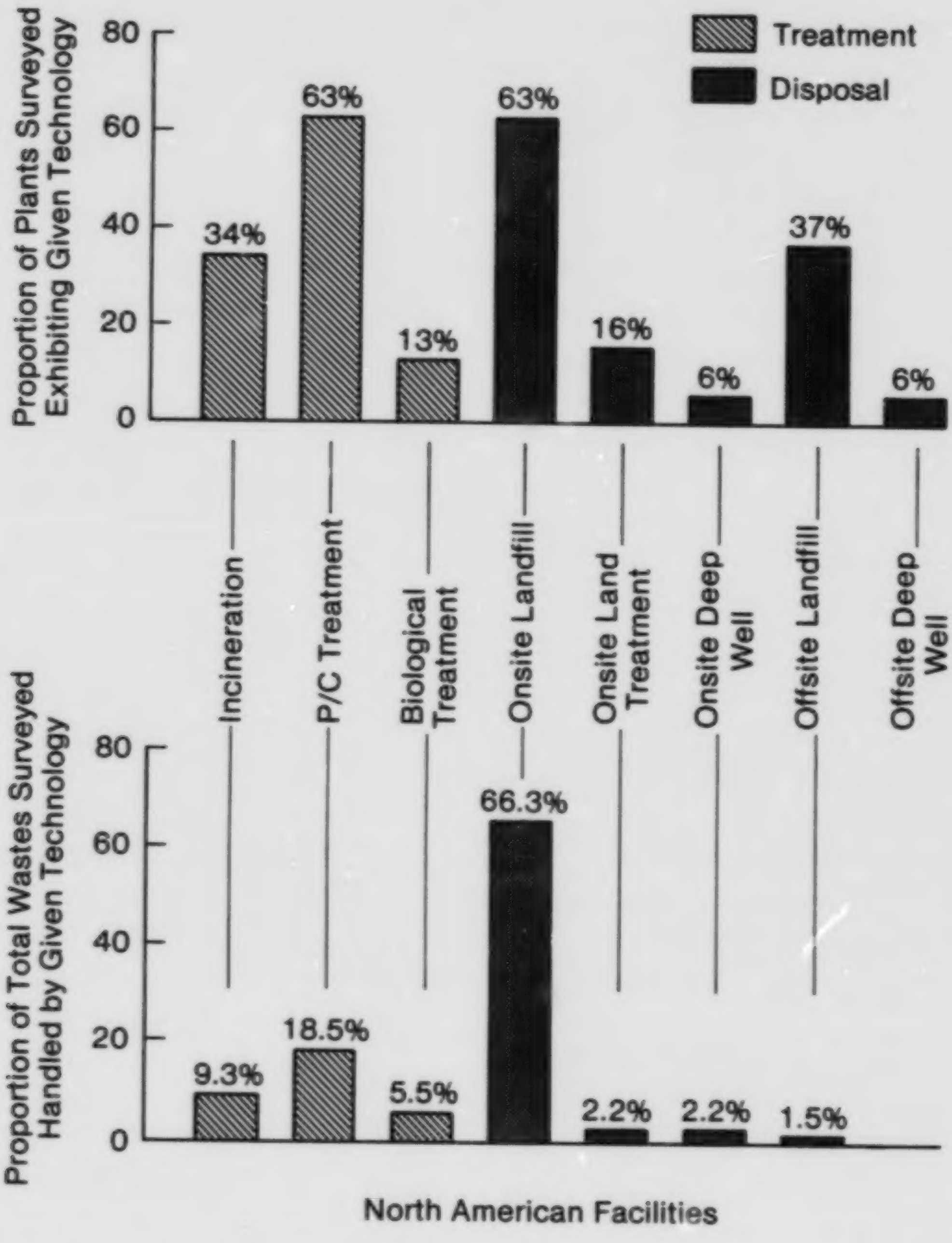


Figure 3. Proportion of plants and proportion of wastes according to technology for North American facilities.

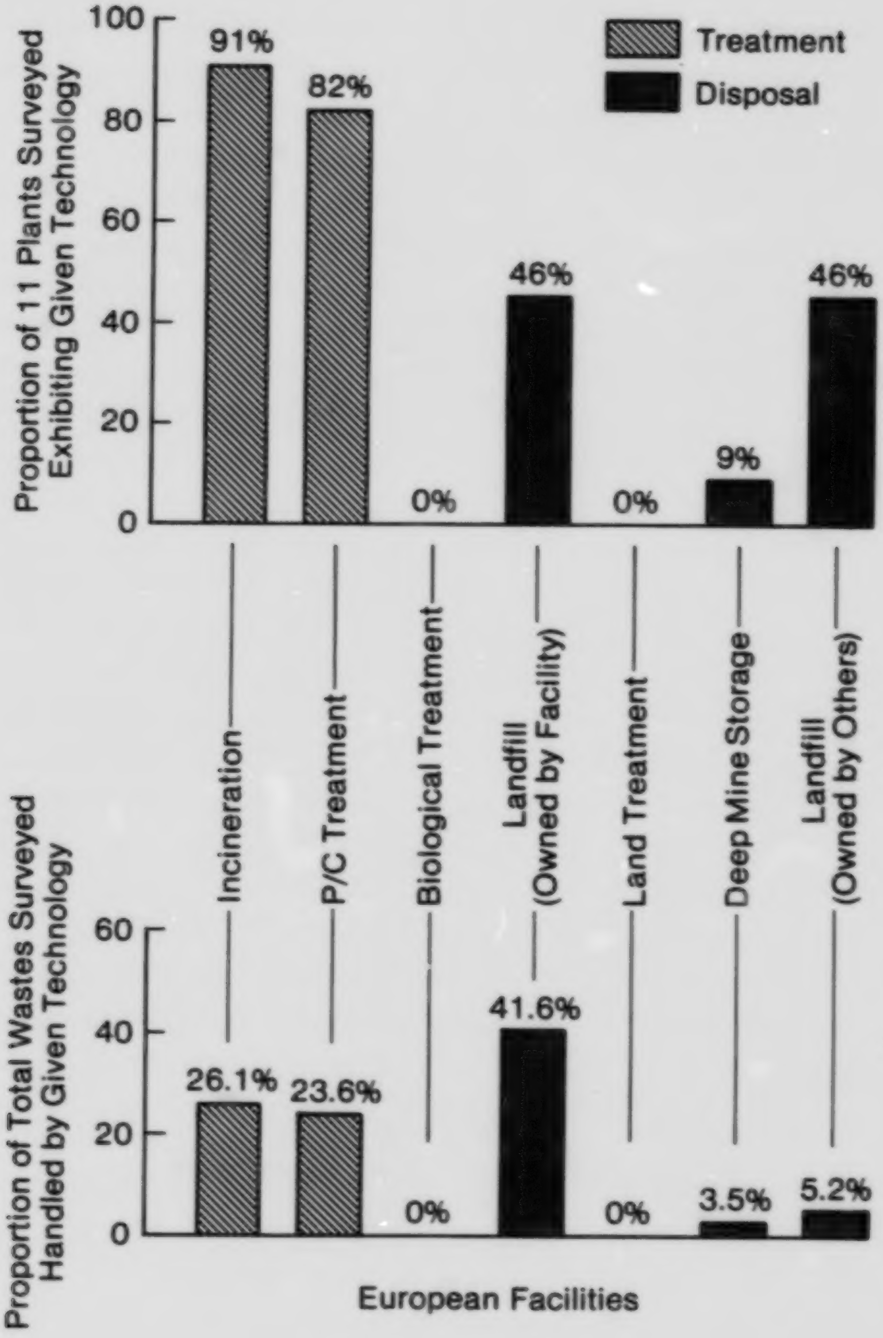


Figure 4. Proportion of plants and proportion of wastes according to technology for European facilities.

9.3% of the total waste tonnage handled. Likewise, two thirds of these facilities employ physical/chemical treatment, but this accounts for only 18.5% of the total waste tonnage handled. On the other hand, all facilities had some landfill option (63% onsite, 37% offsite) and this disposal method accounted for 67.8% of the total waste tonnage handled. Although some proportion of the landfilled tonnage corresponds to residues from treatment processes, as opposed to untreated wastes, this proportion could not be directly deduced from the waste quantity data collected. One overlap which was found was the 5.5% for biologically treated waste tonnage which also received physical/chemical treatment. Since this overlap could be recognized in the raw data, this quantity was not duplicated in the total waste tonnage for the purposes of calculating percentages. Consequently, a summation of percentages in Figure 3 will exceed 100% because the 5.5% for biologically treated wastes is shown as a separate entry.

The summary in Figure 4 shows an interesting comparison for European facilities. Although a higher proportion of waste tonnage is handled by the much higher number of incineration and physical/chemical treatment plants, 46.8% of all waste tonnage handled was still disposed to landfill. This proportion rises to 50.3% if the deep mine storage is included. Clearly, given the higher proportion of treatment processing for European plants, a higher proportion of landfilled wastes will be contributed from treated residues.

The actual waste proportion values are the result of estimates rather than hard data. However, it should be clear that, even when considering wastes handled by high technology, centralized facilities in Europe, approximately half of the waste tonnage, treated or not, ultimately ends up in landfill or perpetual storage.

3.3 TECHNOLOGY CONSIDERATIONS FOR ALBERTA

Since the Alberta facility must operate in the North American economic and industrial climate, the proportion of wastes which must be landfilled will likely be at least as high as estimated for European facilities and it may tend more towards the 70% average apparent for North American facilities. In any case, the data evaluated were obtained from a major cross-section of the current hazardous waste service industry and they clearly demonstrate the importance of the landfill as a central component of the overall facility.

The foregoing observation seems to run contrary to the recent California policy of banning hazardous waste disposal to land as of 1983 January 01 (Brown 1981). However, closer examination of this policy, considering the data provided by the Toxic Waste Assessment Group (1981), indicated that the policy only applies to approximately 500 000 t/a of the estimated 1 300 000 t/a of hazardous wastes generated in California. Furthermore, about 270 000 t/a of the banned wastes are metal wastes which would most likely have to go to land after some processing (i.e., precipitation) since economics are unlikely to allow significant recovery of these metals in the near future. If stabilized metal wastes are land disposed, some 82% of the California hazardous waste total could still be land disposed under the California land disposal ban.

Applying the California policy to the Alberta inventory estimate of 89 000 t/a (Reid Crowther 1980), approximately 16 000 t/a would be banned from landfill. However, close to 7000 t/a of this total could be stabilized for land disposal. Thus, almost 90% of the estimated waste inventory for Alberta could be landfilled in accordance with the California ban on hazardous waste disposal to landfill. Of the remaining 9000 t/a, 7000 t/a would be incinerable. Therefore, even given an apparently restrictive policy on landfill disposal of hazardous wastes, the landfill is still a dominant component of the facility.

To gain an appreciation of the scale of a prospective Alberta landfill facility, assuming 70% of the estimated 89 000 t/a were land disposed, the following calculation is informative. Assuming approximately 60 000 t/a of waste with a nominal density of 1 t/m^3, the net landfill volume required per year could be contained in a cell 50 m x 100 m x 12 m deep (165 ft. x 330 ft. x 40 ft. deep). This requires a surface area of about the equivalent of 10 residential single family dwelling lots. Clearly, the scale of land fill operation, based upon these loose estimates, is not large. Therefore, it should be possible, given a reasonable pricing policy, to provide a landfill which employs the best available technology to minimize any potential for problems.

4. RESIDUE GENERATION

All of the candidate technologies identified in Section 3 generate residues to some degree. Thus, regardless of the treatment technology employed, some quantity of residue may be expected. This chapter considers available information on the quantity and quality of residues generated.

4.1 PHYSICAL/CHEMICAL TREATMENT

4.1.1 Neutralization

In environmental engineering practice, neutralization refers to the general concept of returning wastewater pH to levels within an environmentally acceptable range, generally from pH 6 to 9. Specific constraints for a given waste may necessitate tighter pH criteria.

The factor controlling the quantity of neutralization reagent required is the buffering capacity of the waste (ie., the ability of the waste to resist a change in pH). Poorly buffered wastes will respond with major pH changes for small additions of acid or alkali, while highly buffered wastes will require greater additions before exhibiting significant pH change.

The quantities of residue generated by neutralization processes will depend on a number of waste-specific factors including:

1. buffering capacity;
2. initial pH (acidic or basic);
3. neutralizing agent used;
4. dissolved solids content; and
5. suspended solids content.

The initial pH will determine whether an acid or base will be required to neutralize the waste to an acceptable pH range. If acid addition is required, sulphuric (H_2SO_4) and hydrochloric (HCl) acids are most commonly used. Sulphuric acid will form more insoluble precipitates than hydrochloric acid.

If a base is required, calcium, magnesium, and sodium reagents are commonly used. Calcium reagents ($Ca(OH)_2$, CaO or

$CaCO_3$) produce the largest quantity of residue. Mixed calcium/magnesium reagents ($CaO.MgO$, $CaCO_3.MgCO_3$) will produce lower residue quantities. Sodium reagents ($NaOH$, $NaHCO_3$, Na_2CO_3) will produce the lowest residue quantities. In fact, they may not precipitate solids beyond the influent suspended solids content in the waste. A typical neutralization process scheme is depicted in Figure 5.

Neutralization chemical costs are generally inversely related to residue generation potential. The relatively small quantities of waste normally treated in hazardous waste facilities might suggest advantages for the chemicals with low residue generation potential. However, materials which are not precipitated as residues in the process will remain with the liquid phase. Overall waste management objectives will usually be better met by transferring contaminants to the solid residue phase.

Given the variable factors controlling residue generation in neutralization processes, the residue quantities are likely to be highly variable. Estimates from operating plants ranged from a low of .003 t residue/t wastewater (Cecos site visit, 1982) to a high of 0.4 t residue/t of wastewater (Liqwacon/Envirite site visit, 1982). Two plants reported mid-range values of 0.1 t residue/t wastewater (GSB site visit, 1981; American Recovery site visit, 1982).

The characteristics of residues from neutralization are entirely dependent upon the characteristics of the waste being treated. Generally, the ions combining with the acid or base reagent to form insoluble salts will be relatively innocuous. Hazardous properties would be mainly associated with any toxic metals precipitated. Such characteristics will be covered in Section 4.1.4.

4.1.2 Oxidation

Individual chemical constituents exist in a variety of oxidation states determined by the number of electrons present in their atomic orbitals. The chemical characteristics of a given

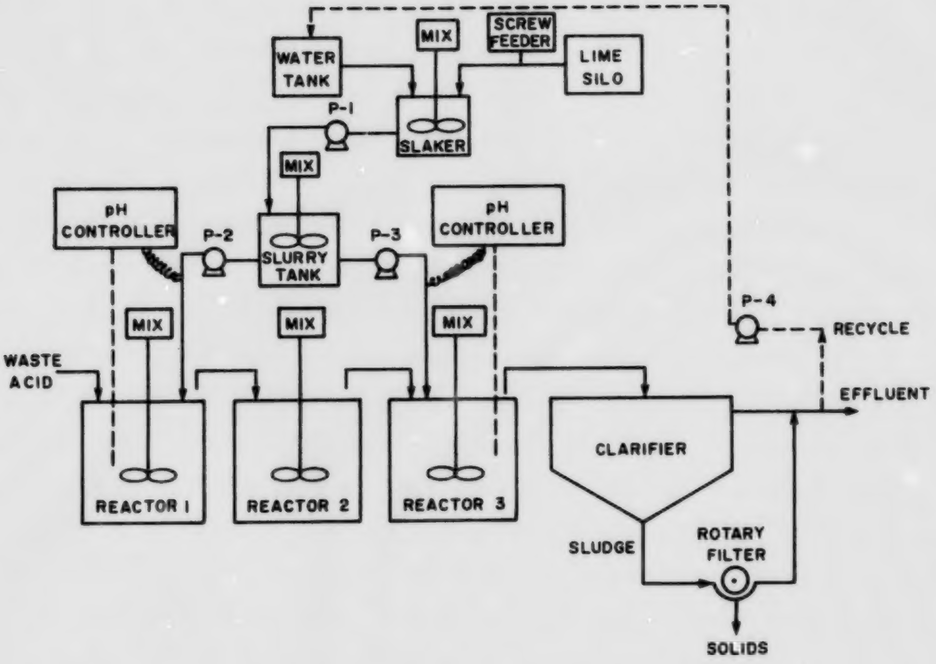

WATER TANK
MIX
SCREW FEEDER
LIME SILO
P-1
SLAKER
MIX
pH CONTROLLER
P-2
SLURRY TANK
P-3
pH CONTROLLER
P-4
RECYCLE
MIX
MIX
MIX
WASTE ACID
EFFLUENT
CLARIFIER
REACTOR 1
REACTOR 2
REACTOR 3
SLUDGE
ROTARY FILTER
SOLIDS

Figure 5. Process schematic for neutralization (EPA 1980).

compound often change dramatically with a change in oxidation state. Thus, it is often possible to detoxify or separate a toxic compound by changing its oxidation state through the removal of electrons, or oxidation. For example, free cyanide, CN^-, is considerably more toxic than cyanate, CnO^-. Hence, oxidation to cyanate can significantly reduce the toxicity of cyanide.

Various chemical reagents function effectively as oxidizing reagents. Those most commonly encountered are chlorine (including chlorine gas and hypochlorite salts, Cl_2 and OCl^-), ozone (O_3), chlorine dioxide (ClO_2), and hydrogen peroxide (H_2O_2).

Alkaline chlorination of cyanide is often employed for metals industry wastewaters which are commonly rich in cyanides. This process may be shown as:

$$CN^- + 2OH^- + Cl_2 \longrightarrow CNO^- + 2Cl^- + H_2O$$

The cyanate can be further oxidized by excess chlorine:

$$2CNO^- + 3Cl_2 + 4OH^- \longrightarrow 2CO_2 + N_2 + 6Cl^- + 2H_2O$$

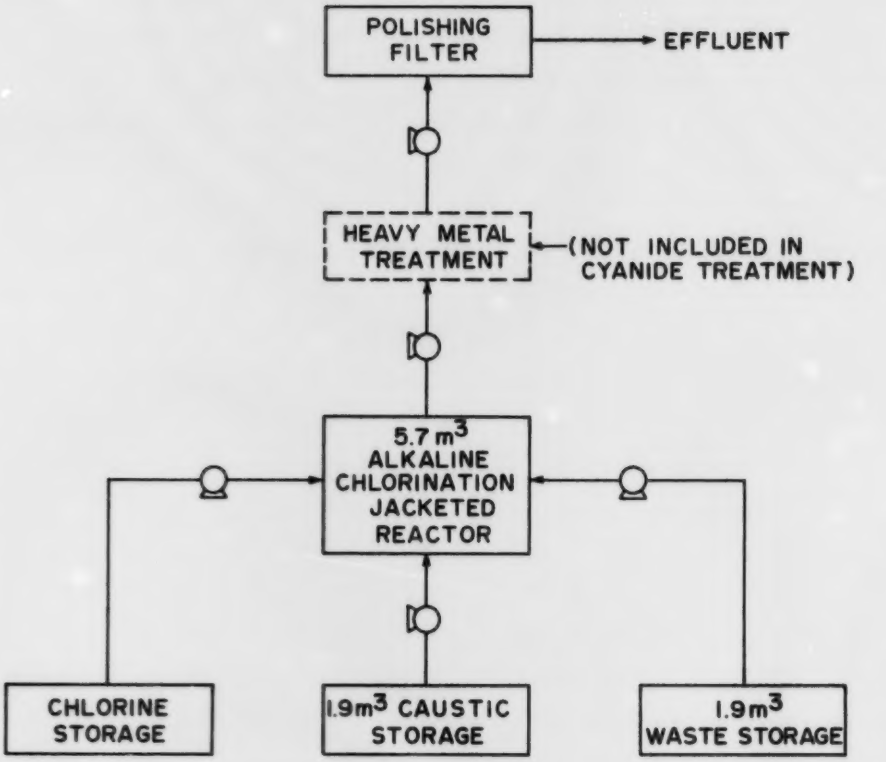
This particular process is depicted in Figure 6.

Oxidation reagents are not specific and will be consumed by any oxidizable (reduced) species present in the waste. Hence, if interfering species are present, in significant concentrations relative to the contaminant of interest, chemical consumption will be undesirably high.

Many oxidation reactions are very pH dependent, and efficient oxidation requires careful pH control. As well, some reaction conditions can become hazardous under inappropriate pH conditions. For example, cyanide ion will form toxic hydrogen cyanide gas (HCN) under acidic conditions.

Although quantities of residue produced by this process can be variable, they were generally reported to be insignificantly small. The major factor controlling the amount of residue generated would be the concentration of metals in the wastewater which would precipitate at the pH (usually about 8.5) of the process.

Characteristics of the residues from this process will be mainly determined by the metals which can be precipitated. Cyanide content of the residue should not be a problem since excess


POLISHING FILTER
EFFLUENT
HEAVY METAL TREATMENT
(NOT INCLUDED IN CYANIDE TREATMENT)
5.7 m3 ALKALINE CHLORINATION JACKETED REACTOR
CHLORINE STORAGE
1.9m3 CAUSTIC STORAGE
1.9m3 WASTE STORAGE

TREATMENT: BATCH

WASTE: CONCENTRATED CYANIDE WASTE
7000ppm COPPER CYANIDE
1000ppm SODIUM CYANIDE

WASTE PROCESSING CAPACITY: 3.8 m^3/d

OPERATING PERIOD: 240 d/yr
8 hr/d

UTILITIES SUMMARY:
5.7 m^3/d COOLING WATER
43 kg/d NaOH
103 kg/d CHLORINE

Figure 6. Process schematic for alkaline chlorination (EPA 1980).

chlorination to insure complete destruction is easily employed. Furthermore, the cyanides will remain in the liquid phase.

4.1.3 Reduction

As noted in the previous discussion on oxidation, the oxidation state of a chemical can be instrumental in determining its hazardous properties. In some cases, it may be possible to decrease the degree of hazard by chemically reducing the compound with the addition of electrons. For example, hexavalent chromium (Cr^{6+}) as found in CrO_4^{2-} is more toxic than the reduced, trivalent chromium (Cr^{3+}). As well, Cr^{3+} can be readily precipitated from solution, whereas the Cr^{6+} occurs in the anionic form (CrO_4^{2-}) which cannot be readily precipitated. Hence, chemical reduction would be advantageous for reducing the hazards associated with chromium.

Various chemicals function effectively as reducing reagents, including: sulphur dioxide (SO_2); and sulphite salts (SO_3^{2-}), bisulphite salts (HSO_3^-),and ferrous salts (Fe^{2+}).

Generally, sulphur dioxide is the most commonly used reducing agent for the treatment of hexavalent chromium. Sulphur dioxide, which can be obtained by burning elemental sulphur, is dissolved in water to yield sulphurous acid according to:

$$SO_2 + H_2O \longrightarrow H_2SO_3$$

The resulting sulphite ion (SO_3^{2-}) can then reduce hexavalent chromium according to:

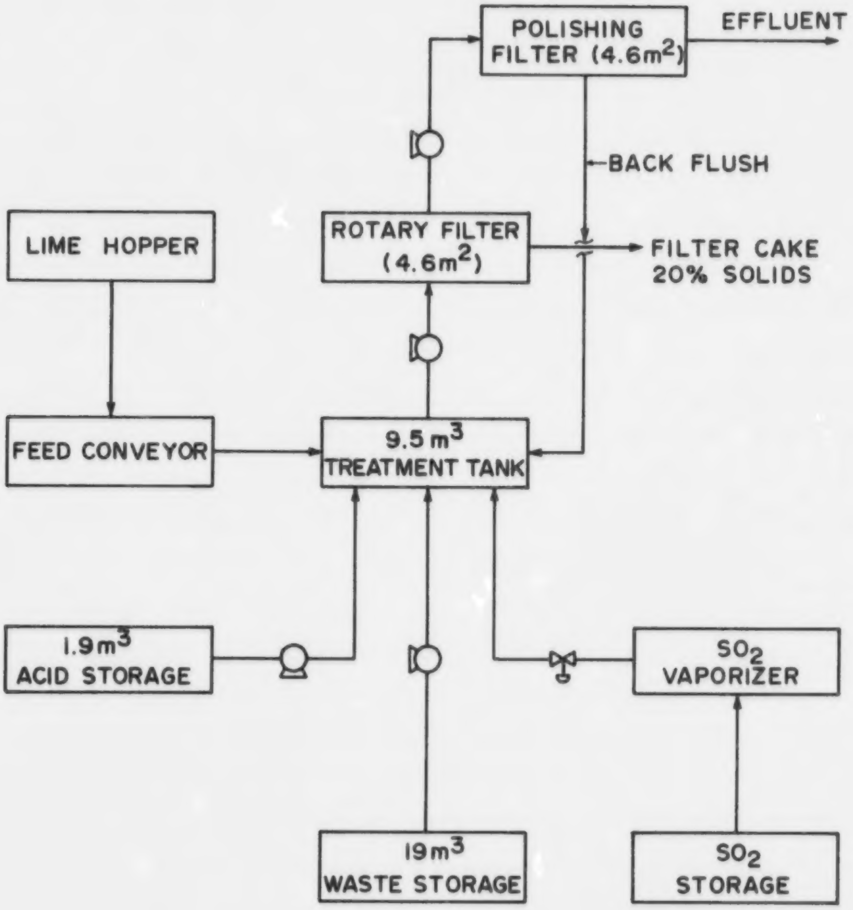
$$2H_2CrO_4 + 3H_2SO_3 \longrightarrow Cr_2(SO_4)_3 + 5H_2O$$

Soluble chromium (Cr^{3+}) is still regarded as toxic and is usually removed through alkaline precipitation according to:

$$Cr_2(SO_4)_3 + 3Ca(OH)_2 \longrightarrow 2Cr(OH)_3\downarrow + 3CaSO_4$$

The sulphite chromate reduction process is depicted in Figure 7.

Another approach to chromium reduction is the use of ferrous sulphate. This process is suitable for small scale application because of its simplicity, but on a larger scale it is regarded as unfavourable due to excessive sludge production. The process proceeds according to:


POLISHING FILTER (4.6m^2)
EFFLUENT
BACK FLUSH
LIME HOPPER
ROTARY FILTER (4.6m^2)
FILTER CAKE 20% SOLIDS
FEED CONVEYOR
9.5 m^3 TREATMENT TANK
1.9m^3 ACID STORAGE
SO_2 VAPORIZER
19m^3 WASTE STORAGE
SO_2 STORAGE

TREATMENT: BATCH

WASTE: CONCENTRATED CHROME WASTE
100,000ppm CrO_3; 85% AS Cr^{+3}
IN 20% H_2SO_4

WASTE PROCESSING CAPACITY: 7.6 m^3/SHIFT

OPERATING PERIOD: 240 d/yr
8 hr/d

RAW MATERIALS:
109 kg/d SO_2
939 kg/d LIME

Figure 7. Process schematic for chromate reduction (EPA 1980).

$$2Na_2CrO_4 + 6FeSO_4 + 8H_2SO_4 \longrightarrow$$
$$Cr_2(SO_4)_3 + 3Fe(SO_4)_3 + 2Na_2SO_4 + 8H_2O$$

This process is conducted at a pH of 2.5 to 3.0 and generally is performed with more than the stoichiometric dosage of ferrous sulphate in order to complete the reaction with reasonable detention times.

Reducing agents, similar to oxidizing agents, are not selective or specific. Thus, it is necessary to insure that the species of interest is not over-shadowed by other reducible compounds which will cause excessive chemical consumption.

Chemical reduction of Cr^{6+} followed by alkaline precipitation will generate significant quantities of residue. The stoichiometry of $Cr(OH)_3$ production predicts 2 kg of sludge per kg of Cr^{6+} treated. Plants with experience reducing chromium wastes reported approximately 0.4 t of residue (at only 10% solids) per t of wastewater treated (Chempro site visit, 1982).

The characteristics of residue generated from this process are largely based upon the characteristics of $Cr(OH)_3$ as the dominant constituent.

4.1.4 Precipitation

The solubility of ionic species in water is governed by many factors such as pH, ionic strength, and temperature. Some combinations of anion and cation form relatively insoluble compounds. Often, a toxic species can be combined with added reagent ions to form an insoluble salt. This process, termed precipitation, is particularly important for the removal of soluble metals from wastes.

Most toxic metals will form relatively insoluble precipitates with hydroxyl (OH^-) and sulphide (S^{2-}) ions. In order to do so, the metals must be available as the free ionic forms which can combine with the precipitating anions. Thus, metals which are bound to soluble cyanide complexes cannot be precipitated until the cyanides are destroyed by a process such as oxidation. As well, soluble anionic forms of metals such as the $CrO_4{}^{2-}$ form of chromium cannot be precipitated until the Cr^{+6} is reduced to Cr^{+3}.

Wastes processed by hazardous waste plants are most commonly precipitated as hydroxides. This can be achieved by adding a base, usually lime, to raise the pH. Lime addition will precipitate insoluble metal hydroxides as well as insoluble calcium compounds.

The quantities of residue from precipitation processes are highly variable. They will be primarily governed by the soluble metal content of the waste and the corresponding lime dosage for hydroxide precipitation. Typical values in the range of 0.1 to 0.3 t of residue per t of waste processed were reported (ZVSMM site visit, 1981).

The characteristics of precipitate residues will largely be determined by the metal composition of the waste. Hydroxide sludges have been found to be relatively resistant to leaching of metals except for low pH extraction solutions (American Electroplaters Society 1981).

4.1.5 Oil/Water Separation

Hydrocarbon wastes are often intermixed with water and inorganic solids. Such waste oils may be segregated from the water phase, primarily on the basis of specific gravity differential. Provided that the inorganic content is low, oils may exhibit enough specific gravity differential to allow gravity separation. More commonly, the oily phase will be dispersed as fine droplets throughout the liquid phase in the form of an emulsion. In such cases, emulsion-breaking must be pursued before gravity separation will be possible. Common emulsion-breaking techniques include acidification, heat treatment, and electrostatic and chemical demulsification. The success of any technique will be determined by the particular characteristics of the waste emulsion. Usually chemical demulsification with coagulating agents such as alum or ferric chloride will succeed for most waste emulsions. High dosages of such chemicals may be required to destablize some emulsions. The success of acidification, heat treatment, and electrostatic processes is more dependent on the particular waste characteristics.

In cases where inorganic content of the waste mixture is high, centrifugation may be desirable to efficiently separate sludge, provided the combination of oil and inorganic solids does not approach unit specific gravity.

The quantities of residue (materials other than oil and water) generated by oil/water separation processes will generally be governed by the inorganic content of the waste oils. Where coagulating chemicals are used for emulsion breaking, their dosage rate will determine the quantity of residue produced. The specific quantities in these cases can be estimated from the stoichiometry of $Fe(OH)_3$ or $Al(OH)_3$ produced by treatment with $FeCl_3$ or $Al_2(SO_4)_3$ respectively. One plant using thermal and chemical demulsification estimated less than 0.01 t of residue (at 30% solids) per t of emulsified oily wastewater treated (Chempro site visit, 1982). In another case, thermal demulsification produced an estimated 0.1 t of residue per t of waste oil/water treated (Toffner-Clausen 1982).

The residues produced from an oil/water separation process will generally have a high organic content and may also contain toxic metals such as lead. Provided the lead content is acceptably low, these residues are often suitable for incineration, although their thermal content is generally inadequate to sustain efficient combustion.

4.1.6 Solvent/Fuels Recovery

Waste solvents may be reclaimed either for reuse as solvents or for use as fuels. Generally, halogenated solvents are more economically attractive for reuse. Recovery processes may range from simple decanting to filtration and distillation.

The quantities of residue produced from these processes are variable since quantities depend entirely on the solids content of the waste solvents. Three plants reported a range from 0.1 to 0.2 t of residue per t of waste solvent received. (Chempro site visit, 1982; Applied Environmental Services site visit, 1982; Lovgren 1982).

The characteristics of residues will vary from organic contaminated clays to predominantly organic tars. In many cases, these materials are suitable for incineration although their heat value will be determined by the residual organic content.

4.1.7 Adsorption

Adsorption processes utilize the affinity of individual water contaminants for a solid adsorbent surface to achieve removal of the pollutant from the liquid phase. As such, the pollutants are transferred from the wastewater but are not destroyed by this process.

The most common adsorbent used for hazardous waste treatment is activated carbon. It is useful because of its wide range of affinity for a variety of wastewater contaminants.

Residue generation from the process will arise from the spent adsorbent itself. Although activated carbon can be regenerated at high temperature, the efficiency of regeneration is reduced by inorganic contaminants. Since these may be a problem for many mixed hazardous wastes, the residue generation rate would be determined by the exhaustion rate of the adsorbent. That, in turn, would be determined by the concentration of adsorbable species in the waste. No estimates were obtained of residue generation by this process.

Spent activated carbon will contain significant concentrations of contaminants which can subsequently desorb. However, activated carbon can be efficiently incinerated because of its high heating value.

4.1.8 Summary for Mixed Physical/Chemical Wastes

The quantities of residue generated by the various physical/chemical treatment processes reviewed are clearly controlled by the characteristics of the incoming wastes. This fact makes it difficult to estimate residue quantities from individual processes on a generalized basis.

Given the foregoing, it is useful to note the experience of some plants performing a variety of processes on a mixture of wastes. Two integrated plants reported from 0.4 to 0.5 t of residue per t of waste processed (HIM-Frankfurt site visit, 1982; Henriksen 1982). On the other hand, a much lower value of 0.1 t of residue per t of waste processed was reported for a similar integrated plant (GSB site visit, 1982)

4.2 BIOLOGICAL TREATMENT

As noted in Section 3, biological treatment is not widely used for hazardous waste treatment. However, this process category will be included for completeness. All biological processes encountered during this survey were some form of the activated sludge process.

4.2.1 Activated Sludge

Activated sludge involves mixing incoming wastewater with a suspension of microbial biomass in aeration basins. During the mixing process, soluble and colloidial organic matter can be assimilated from the wastewater into the biomass. Aeration is provided to sustain an aerobic environment recognizing the metabolic oxygen demand of the biomass as it assimilates and oxidizes organic matter from the wastes. Aeration also provides the mixing required to insure adequate contact between the biomass and the soluble organics by keeping the biomass in suspension. Following adequate contact time in the aeration basin (four to eight hours in conventional activated sludge, 18 to 36 hours in extended aeration) the mixture of wastewater and biomass, referred to as mixed liquor, is allowed to settle in a clarifier. Under proper operating conditions, the biomass will flocculate and settle, leaving a treated supernatant as effluent for discharge.

The biomass grows on the organic carbon provided by the wastewater. In order to provide high mass transfer and waste assimilation in the aeration basin, the majority of settled biomass (or activated sludge) is recycled to the aeration basin. However, since the sludge biomass is constantly growing on wastewater organic carbon while self-degrading at a lesser rate, sludge will accumulate in the system unless some fraction is wasted. Sludge wastage from the system is performed at a rate determined to sustain a desirable process organic loading rate expressed as g of substrate organic carbon per g of sludge biomass per day. This quantity, often termed the food to microorganism ratio or F/M, is usually maintained in a desirable operating range by controlling the mean cell residence time (or sludge age). The latter is calculated as the total inventory of biomass divided by the biomass wastage from the system. Under conditions approaching steady state, controlling the mean cell residence time will control the food to microorganism ratio.

Biological reaction systems present a wide variety of operational problems. Many of these result from the system dependence upon living organisms to perform the treatment.

Some hazardous materials are resistant to biodegradation and will either accumulate on the sludge, rendering it hazardous, or pass through the system in the effluent. Others may be partially or totally degradable but may exert toxic or inhibitory effects upon the biomass, impairing its overall treatment performance. Even without improving substrate assimilation or degradation, poor performance can result from degradation of sludge settling performance which can lead to discharge of biomass solids in the effluent. In the extreme, loss of sludge settleability can lead to process failure by preventing an adequate rate of biomass return to the aeration chamber.

The quantity of residue produced will be a function of the organic load upon the plant. Reported residue generation for activated sludge plants based on five site visits ranged from .001 to .008 t residue/t of waste processed (Dupont Chambers Works site visit, 1981; Rollins Deer Park site visit, 1982; BASF Ludwigshafen site visit, 1982; Hoeschst Frankfurt site visit, 1982; and Bayer Leverkusen site visit, 1982). The wide range was mainly attributable to differing degrees of sludge dewatering. The values were consistent at the lower end of the range for sludges with a high degree of dewatering (to 40% solids).

The characteristics of residues from biological treatment will also be highly dependent upon the degree of dewatering performed. With high solids content, it is feasible to incinerate the organic residues. In fact, BASF has developed a process they call "Carbosed", whereby coal is used to aid dewatering which makes the resulting solids a better fuel for incineration. However, landfill of biological sludges is still the most common disposal option, largely because of the large sludge quantities involved. Landfarming of biological sludges from treatment of hazardous wastes is usually limited by toxic metal content and/or concern with desorbing of toxic organics.

4.3 INCINERATION

Organic contaminants present in hazardous wastes may be effectively destroyed by performing oxidation using thermal energy. In idealized thermal oxidation, organic materials can be oxidized to carbon dioxide, water, and various trace gases such as sulphur oxides, nitrogen oxides, and hydrogen chloride. In actual practice, wastes will contain some inorganic residues which can harbour combustible materials and lead to some degree of incomplete combustion.

Successful thermal oxidation is dependent primarily on three process factors: temperature, residence time, and turbulence. Temperature is important because any organic contaminant will have a maximum upper temperature beyond which it is thermally unstable and subject to combustion. Selection of an incineration temperature uniformly above this ignition temperature will assure complete destruction given satisfactory components of residence time and turbulence. The residence time is critical because combustion kinetics and heat transfer limitations require that a given molecule of contaminant must be exposed to the specified temperature for some finite time period to insure complete combustion. This is usually assured by providing a sufficiently long average residence time for the total waste flow. Finally, adequate turbulence is required to insure that complete combustion is not inhibited by inadequate mass and heat transfer within the combustion chamber.

Of the many possible incineration systems, rotary kilns and liquid injection incinerators are the designs most commonly employed at hazardous waste facilities.

4.3.1 Rotary Kiln Incinerators

A rotary kiln is essentially a cylindrical, steel chamber, lined with refractory brick, which can be rotated about its longitudinal axis by a gear drive. Solid and pasty wastes can be fed to the kiln inlet by overhead grabs. Drums can usually be fed into the kiln via an elevator system. Kilns are generally operated between 900°C and 1400°C. While residence time of the solids may be hours, the combustion gases have only seconds of residence time in the kiln. Assurance of complete combustion is usually achieved with an after burner chamber which receives thermally rich liquid wastes directly. These can operate at temperatures greater than 1400°C as required. These high temperatures and the extended residence times in the after burner are desirable to assure complete combustion. Flue gases may be cooled by heat recovery in a waste heat boiler. If thermal recovery is not practiced, it would be necessary to cool the flue gases prior to entering particulate removal and acid gas scrubbing systems. The rotary kiln incineration system is depicted in Figure 8.

Bonner et al. (1981) presented the following advantages and disadvantages for rotary kiln incinerators.

Advantages

1. Kilns will incinerate a wide variety of liquid and solid wastes.
2. Kilns will incinerate materials passing through a melt phase.
3. Kilns are capable of receiving liquids and solids independently or in combination.

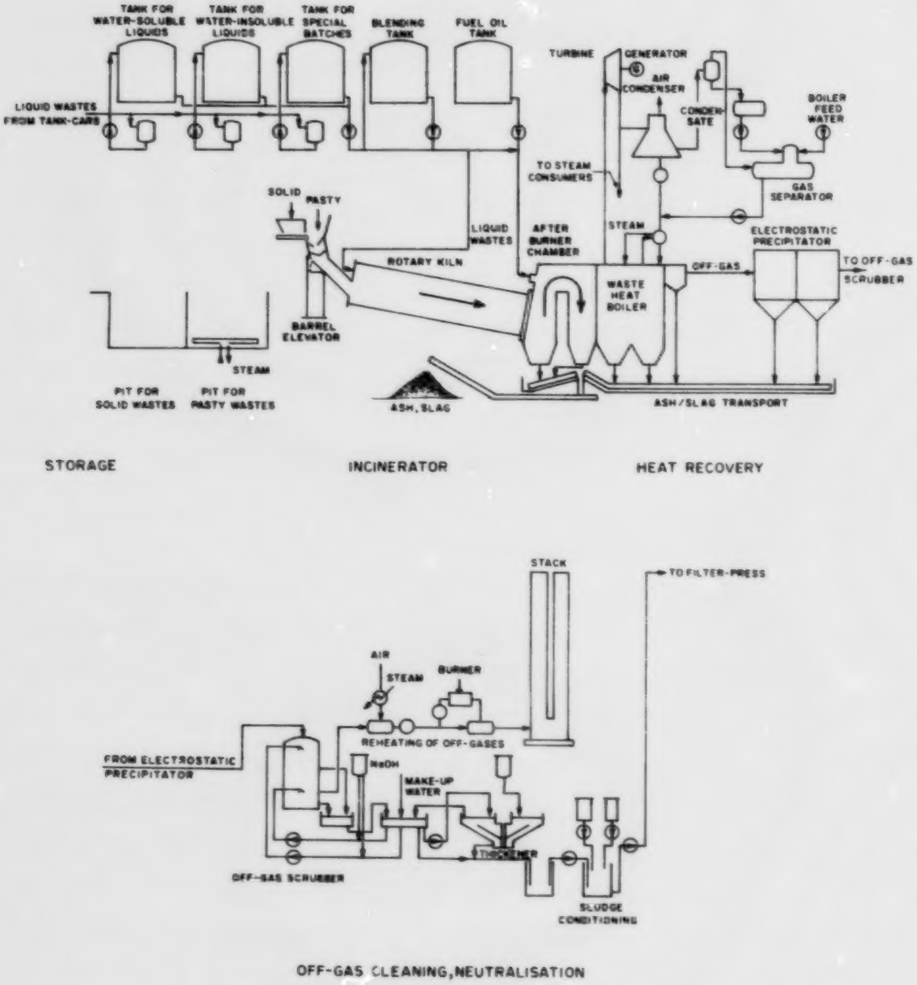

TANK FOR WATER-SOLUBLE LIQUIDS
TANK FOR WATER-INSOLUBLE LIQUIDS
TANK FOR SPECIAL BATCHES
BLENDING TANK
FUEL OIL TANK
LIQUID WASTES FROM TANK-CARS
TURBINE
GENERATOR
AIR CONDENSER
CONDENSATE
BOILER FEED WATER
TO STEAM CONSUMERS
GAS SEPARATOR
SOLID
PASTY
LIQUID WASTES
AFTER BURNER CHAMBER
STEAM
ELECTROSTATIC PRECIPITATOR
ROTARY KILN
OFF-GAS
TO OFF-GAS SCRUBBER
WASTE HEAT BOILER
BARREL ELEVATOR
STEAM
PIT FOR SOLID WASTES
PIT FOR PASTY WASTES
ASH, SLAG
ASH/SLAG TRANSPORT
STORAGE
INCINERATOR
HEAT RECOVERY
STACK
TO FILTER-PRESS
AIR
STEAM
BURNER
REHEATING OF OFF-GASES
FROM ELECTROSTATIC PRECIPITATOR
NaOH
MAKE-UP WATER
THICKENER
OFF-GAS SCRUBBER
SLUDGE CONDITIONING
OFF-GAS CLEANING,NEUTRALISATION

Figure 8. Process schematic for rotary kiln incineration (GSB 1982, site visit).

4. Kilns can be fed drums and bulk containers.
5. Kilns are adaptable to a wide variety of feed mechanism designs.
6. Kilns provide high turbulence and air exposure of solid wastes.
7. Continuous ash removal does not interfere with the waste oxidation.
8. There are no moving parts inside the kiln (except when chains are added).
9. Kilns are adaptable for use with a wet gas scrubbing system.
10. The retention or residence time of the non-volatile component can be controlled by adjusting the rotational speed.
11. The waste can be fed directly into the kiln without any preparation such as preheating or mixing.
12. Rotary kilns can be operated at temperatures in excess of 1400°C, making them well suited for the destruction of toxic compounds that are difficult to thermally degrade.
13. The rotational speed control of the kiln also allows a turndown ratio (maximum to minimum operating range) of about 50%.

Disadvantages

1. The capital cost for kiln installation is high.
2. Operating care is necessary to prevent refractory brick damage. Thermal shock is a particularly damaging event.
3. Airborne particles may be carried out of a kiln before complete combustion.
4. Spherical or cylindrical items may roll through a kiln before complete combustion.
5. The rotary kiln frequently requires additional makeup air due to air leakage via the kiln end seals.

6. Drying or ignition grates, if used prior to the rotary kiln, can cause problems with melt plugging of grates and grate mechanisms.
7. Particulate loadings to combustion gases from kilns will be high.
8. Thermal efficiency of kilns is relatively low.
9. Problems in maintaining seals at either end of the kiln can be a significant operating difficulty.

Inorganic residues present in the waste feed will lead to slag formation. The slag can attack the refractory lining both chemically and mechanically. Usually it is necessary to subject the refractory lining to periodic maintenance and replacement because of slag induced damage.

Residues from rotary kiln incinerators will arise from the inorganic bottom ash (slags and non-combustible solids), fly ash (from particulate removal), and scrubber sludges (from acid gas scrubbing). Each residue category will have different generation rates and characteristics.

4.3.1.1 Bottom ash residues. These are primarily determined by the bulky inorganic content of the feed wastes. Hence, metal drums or drum closures from fibre-pack drums can be a major contributor to bottom ash residue. Table 3 provides estimates of bottom ash residue generation for nine operating rotary kiln incinerators. The wide range observed is the result of significant differences in waste feed characteristics. However, these estimates show that residues from mixed hazardous waste incineration do not generally exceed 0.20 t residue per t of waste incinerated.

Likewise, the characteristics of bottom ash residues from rotary kiln incinerators would be expected to vary considerably depending on waste source. However, given the long retention times for such residues in a rotary kiln, their organic content should be low. These expections have been confirmed in several cases. A test burn with a rotary kiln incinerator (Ackerman et al. 1977) found that PCBs on bottom ash residues were below their detection limit

Table 3. Estimated bottom ash residue generation rates for rotary kiln incinerator facilities.

Residue Generation (t residue/t waste incinerated)	Comments	Source
0.03	estimate for mixed wastes	BASF site visit, 1982
0.03	residue for 90% liquids 10% solids feed	Kodak site visit, 1982
0.05	calculated for ferrous residue	3M site visit, 1982
0.05	estimate for solids/ sludges	Rollins (Deer Park) site visit, 1982
0.10	estimate for burning shredded PCB capacitors	ENSCO site visit, 1982
0.10	estimate for mixed wastes	GSB site visit, 1982
0.16	slag residue calculated from plant mass balance mixed solvent/waste oil	Toffner Clausen 1982
0.17	estimate for mixed wastes	HIM (Biebesheim) site visit, 1982
0.20	estimate for mixed wastes (includes fly ash)	ZVSMM site visit, 1981

(<0.1 mg/kg) when "hammer-milled" capacitors were burned. However, residues exhibited >470 mg/kg of PCBs when "whole" capacitors were burned. However, the PCB quantitation was uncertain due to an observed recovery of only 10% of PCBs spiked onto residue. Another test burn seeking a series of specific organic compounds in residues found them to be generally below their detection limit (Cincinnati MSD site visit, 1982).

Finally, bottom ash residue samples collected during site visits to two European rotary kilns were subjected to hexane/acetone soxhlet extraction and analysis by GC/MS. Table 4 shows the results obtained (Bridle, personal communication 1982). These indicated only trace quantities of some polynuclear aromatic hydrocarbons and some of the ubiquitous phthalate esters.

The inorganic composition of bottom ash residues might be expected to be more interesting. Table 5 provides inorganic analyses of solid residues from the PCB capacitor test burns. Table 6 shows mineral analyses of rotary kiln slags from some European kiln facilities.

4.3.1.2 Flyash. This ash is distinguished from bottom ash since it is entrained in the combustion gases which exit the incinerator. Fly ash is recovered in particulate removal devices, most commonly in electrostatic precipitators. Many installations will functionally combine the acid gas scrubbing and particulate removal processes. In these cases, it will not be possible to distinguish flyash from scrubber sludges. As with bottom ash residue, the composition will be largely determined by the inorganic composition of the waste feed. Flyash will be physically different from bottom ash because individual particles must be small enough to be entrained and carried by the combustion gases.

Table 7 presents mineral analysis of the flyash for the Kommunekemi facility (Kristensen 1982). Compared with the analysis for bottom residue in Table 6, the higher proportion of volatile metals is notable. In particular, lead, zinc, cadmium, arsenic, and mercury are two or more orders of magnitude higher as proportional

Table 4. Rotary kiln bottom ash residue analysis for trace organics.[a]

Compound	Concentrations in $\mu g \cdot g^{-1}$	
	Plant A Bottom Ash	Plant B Bottom Ash
Kiln Temperature	1000°C	850°C
phenol	-	6
acenaphthene	1	-
anthracene/phenanthrene	3	3
fluoranthene	1	1
naphthalene	6	5
pyrene	-	1
n-nitrosodiphenylanine	2	4
butylbenzylphthalate	4	542
di-n-butylphthalate	-	156
diethylphthalate	3	1
bis(2-ethylhexyl)phthalate	13	662
isophorone	29	--

[a] Source: T.R. Bridle, personal communication 1982

Table 5. Analysis of solid residues from PCB test burns.[a]

Element	Concentration (mg/g)	
	Hammermilled Capacitor Test	Whole Capacitor Test
Average Kiln Temperature	1250°C	1340°C
Al	360	180
Ag	0.4	0.5
As	ND(<0.1)	0.9
Ba	0.2	1
Be	ND(<0.001)	0.002
Ca	3	6
Cd	0.04	0.07
Co	<0.01[b]	<0.01[b]
Cr	0.7	0.7
Cu	50	43
Fe	300	400
K	<180[b]	<160[b]
Mg	0.7	1
Mn	0.9	1
Mo	<0.6[b]	<0.5[b]
Ni	0.3	0.4
P	17	13
Pb	7	4
Si	85	100
Sn	13	7
Sr	0.01	0.02
Ti	0.9	1
V	0.1	0.1
Zn	2	5

[a] Source: Ackerman et al. 1977

[b] The less than or equal to values indicate that the sample results were equal to or lower than the reagent blank.

Table 6. Inorganic composition of bottom ash residues from rotary kiln incinerators.

	Composition % by wt.		
Constituent	Kiln 1[a]	Kiln 2[b]	Kiln 3[c]
Average Kiln Temperature	950°C	>1300°C	1000-1500°C
carbon	1.5	0.3 to 1.1	-
SiO_2	3.9	42 to 54	55 to 85
Al_2O_3	3.7	6 to 9	3 to 13
T_iO_2	1.8	0.3 to 0.7	0.5 to 1.5
Fe_2O_3	39	31 to 38	2 to 7
CaO	4.2	3.4 to 4.3	3 to 12
MgO	7.6	0.7 to 0.9	0.5 to 2
Na_2O	2.8	1.7 to 3.4	1 to 3.5
K_2O	1.1	1.3 to 2.9	1 to 2.5
MnO	0.3	0.2 to 0.3(Mn_3O_4)	-
P_2O_5	0.2	2.2 to 3.4	-
PbO	0.2	-	-
ZnO	0.2	-	-
Cr_2O_3	0.2	-	-
CdO	0.0003	-	-
CuO	0.2	-	-
MoO_3	0.1	-	-
V_2O_5	0.1	-	-
SO_3	0.3	-	-
Cl	0.1	-	-
As	0.0003	-	-
Hg	0.00008	-	-

[a] Source: Kristensen 1982
[b] Source: Womann 1979
[c] Source: Fabian et al. 1979

Table 7. Inorganic composition of flyash residues from a rotary kiln incinerator.[a]

Constituent	Composition % by wt.
carbon	2.8
SiO_2	7.8
Al_2O_3	1.4
TiO_2	2.0
Fe_2O_3	4.4
CaO	4.4
MgO	8.7
Na_2O	16
K_2O	5.3
MnO	0.11
P_2O_5	1.2
PbO	6.4
ZnO	4.6
Cr_2O_3	0.54
CdO	0.03
CuO	0.77
MoO_3	0.52
V_2O_5	0.15
SO_3	25
Cl	6.1
As	0.030
Hg	0.011

[a] Source: Kristensen 1982

constituents of flyash. Equally important, Kristensen (1982) reports that the flyash was 47% water soluble compared with only 0.1% for bottom ash residue.

4.3.1.3 Scrubber sludge. These residues arise from scrubbing systems for the removal of acid gases such as HCl. Various scrubber systems are applied but all make use of an alkaline scrubbing medium to neutralize the acid gases. Conventional wet scrubber systems should be distinguished from newer dry or wet/dry systems. The former uses alkaline liquid sprays in conjunction with venturi or packed tower contactors. These require a recirculating water flow which must be continuously maintained alkaline by the addition of sodium or calcium bases. This process creates precipitates which yield the scrubber sludge. Dry systems spray a slurry of lime into the hot gases to achieve acid gas removal. The slurry is dried by the high temperature gases yielding a dry scrubber powder. This powder is not a sludge in the conventional use of the term, but it is included under this heading because of its origins.

For wet scrubbing systems, much of the inorganic matter can accumulate in the recirculating water flow as soluble salts. Although these consitutents will not form part of the scrubber sludge they pose a difficult disposal problem of their own. Part of the recirculating flow must be regularly purged (blowdown) to keep recirculating dissolved solids within acceptable limits. Scrubber effluent was analysed for a series of specific organic compounds during test burns and they were all consistently below their respective detection limits (Cincinnati MSD site visit, 1982).

The quantities of scrubber sludge from wet systems will vary with the neutralizing demands of the waste being burned (i.e., halogen content) since this demand will determine the alkalai dosage. One facility reported the equivalent of .04 t residue (wet) per t of waste incinerated (3M site visit, 1982) for mixed wastes, compared with almost 0.3 t residue (wet) per t of waste incinerated (Rollins Deepwater site visit, 1981) for a more halogenated waste feed. A dry system, on the other hand, generated approximately 0.2

t residue per t of waste incinerated (HIM site visit, 1982). This dry residue is deposited in deep mine storage rather than in secure landfill along with other residues from the HIM plant.

Specific information on the characteristics of scrubber sludge from hazardous waste incinerators was not located. However, work has been done on the characteristics of flue gas desulphurization sludges from power utilities (Weaver et al. 1977; U.S. Army Engineer Waterways Experiment Station 1979).

4.3.2 Liquid Injection Incinerators

A liquid injection incinerator may be a variety of shapes, but the main factor determining its capability is the injection system. Pressurized or mechanical atomization devices allow liquid injection incinerators to process liquids and sludges. The main restriction on a given atomization system is the ability to efficiently atomize viscous liquids or solids in sludges. The many injection systems available have extended the capability of these incinerators over a wide range of waste characteristics.

Bonner et al. (1981) presented the following advantages and disadvantages for liquid injection incinerators.

Advantages

1. Units are capable of incinerating a wide range of liquid wastes.
2. No continuous ash removal system is required other than for air pollution control.
3. Units are capable of a high turndown ratio.
4. Fast temperature response to changes in the waste fuel flow-rate is provided.
5. Virtually no moving parts are required.
6. Low maintenance costs have been found.

Disadvantages

1. Only wastes which can be atomized through a burner nozzle can be incinerated.
2. Heat content of the waste burned must be adequate to maintain ignition and incineration temperatures or

a supplemental fuel must be provided.

3. Burners are susceptible to plugging (burners are designed to accept a certain particle size; therefore, particle size is a critical parameter for successful operation).
4. Burners may or may not be able to accept a material which dries and cakes as it passes through the nozzles.

Because these incinerators cannot accept bulky solids, there is not the same potential for slags and bottom ash residues as occurs with rotary kilns. Flyash quantities would also likely be less, but scrubber sludge quantities would still be determined by the neutralizing demands of the combustion gases. The latter quantities need not be less than found in rotary kilns.

Ash residue for liquid injection incinerators ranged from about .005 t residue per t of waste incinerated (Tricil site visit, 1982) where feed liquids were limited to <1% ash content, to around .01 t residue per t of waste incinerated (ABCO site visit, 1982; Southeastern Waste Treatment site visit, 1982).

Liquid injection incineration of ethylene manufacturing wastes and hexachlorocyclopentadiene was found to leave no detectable trace of these organic compounds on ash residues (Clausen et al. 1977). Table 8 provides inorganic analyses for ash residues from a liquid injection incinerator (Southeastern Waste Treatment site visit, 1982).

Table 8. Composition of ash residues from a liquid injection incinerator.[a]

Constituent	Composition % by wt. Average Incinerator Temperature 850°C
silicon as Si	14.7
aluminum as Al	9.4
titanium as Ti	0.43
iron as Fe	11.3
calcium as Ca	8.0
magnesium as Mg	3.5
manganese as Mn	0.09
lead as Pb	0.6
zinc as Zn	2.4
chromium (III) as Cr	2.6
chromium (VI) as Cr	0.03
copper as Cu	0.07
arsenic as As	0.006
barium as Ba	0.12
selenium as Se	0.0004
silver as Ag	0.007
nickel as Ni	0.14
antimony as Sb	0.003
cobalt as Co	0.0002

[a] Source: Southeastern Waste Treatment site visit, 1982

5. RESIDUE PROCESSING

With the exception of biological treatment sludges, residues from hazardous waste treatment are predominantly inorganic in nature. Thus, they cannot be converted to innocuous gases by combustion. Relatively few other options are available for significantly modifying their form. In fact, only dewatering and stabilization processes are currently used at operating hazardous waste treatment facilities. The residual products of either of these processes must still be disposed.

5.1 DEWATERING

Dewatering, as the name implies, is a process to decrease the water content of a residue. Since most residues described in Section 4 may have significant water content, dewatering can significantly reduce the mass of residue for ultimate disposal. This is particularly important where residues must be transported a substantial distance prior to disposal. As well, water content left in residues can become leachate in a disposal landfill.

Dewatering processes are primarily physical, although chemical aids may be used to release bound water. The driving force for dewatering may be: gravity, as in gravity thickeners; enhanced acceleration, as in centrifuges; or pressure, either positive or negative, as applied in filters.

Theory and applications of sludge dewatering have been well documented by Vesilund (1975) and physical process equipment has been reviewed by Warring (1981). Characteristics and performance of several common dewatering devices are summarized in Table 9 (Crain 1981).

The water produced from dewatering operations will be contaminated with inorganic constituents and possibly organic constituents as well. Treatment options for these waters may be limited to sophisticated desalination technologies, such as reverse osmosis, since the inorganics will be dissolved. However, many of the species, such as the toxic metals, may be reduced through repetition of precipitation processes. Organic constituents may

Table 9. Characteristics of common dewatering devices.[a]

Type	Feed Rate (L/min)	% Solids in Feed	% Feed Solids Retained	% Solids in Output	Capital Investment ($1000)
Thickeners					
Stirred Gravity	50 to 12,000	-	95 to 98	5 to 10	14 to 140
Air Flotation	50 to 40,000	-	92 to 98	5 to 10	28 to 560
Centrifuges					
Disc	100 to 1200	0.2 to 1	90 to 95	5 to 10	28 to 196
Scroll	20 to 1200	0.5 to 15	60 to 95	20 to 45	28 to 280
Basket	50 to 250	1 to 10	90 to 95	5 to 25	28 to 168
Filters					
Vacuum Drum	0 to 1000	8 to 10	50 to 99	20 to 40	7 to 42
Vacuum Belt	5 to 200	5 to 10	75 to 90	15 to 25	21 to 105
Pressure	50 to 1000	2 to 5	95 to 99	20 to 50	7 to 700
Belt	20 to 800	4 to 6	95 to 99	20 to 35	14 to 168
Dual Cell Gravity	50 to 2000	0.05 to 5	90 to 98	10 to 20	-

[a] Source: Crain 1981

require biodegradation or adsorption if present in significant quantity.

5.2 STABILIZATION

The hazard potential of some residues can be significantly reduced by incorporating the waste constituents into a solid matrix. This process can improve the handling and physical characteristics of the waste, decrease the accessible surface area for mass transfer of contaminants from the matrix, and decrease the solubility characteristics of individual contaminants in the waste. Technologies to achieve these objectives are generally referred to as stabilization, fixation, or solidification technologies. They have received considerable attention in recent years (Pojasek 1979a, 1979b). Processes which are specifically applicable to hazardous waste residues have been thoroughly reviewed by the U.S. Army Engineer Waterways Experiment Station (1980).

A wide variety of proprietary technologies are now available to chemically fix wastes. However, most of these techniques can be classified into one of the following categories:

1. cement based processes;
2. pozzolanic processes (not including cement);
3. thermoplastic processes;
4. organic polymer processes;
5. surface encapsulation;
6. self cementing processes;
7. glassification.

The latter five are generally more specialized in application than the cementation processes. They also generally require more expensive feed materials or processing than cementation techniques, although some of these are capable of producing a superior degree of waste isolation in specific applications. The first three processes might have general applicability to hazardous waste residues.

5.2.1 Cement Based Processes

Cement based processes utilize portland cement as the primary solidification agent. This material is the product of high temperature firing of limestone and clay. It consists predominantly of tricalcium and dicalcium silicates with minor quantities of tricalcium aluminate and calcium alumino-ferrite. Cementation is achieved by adding water to the anhydrous powder. Setting to produce the hardened matrix occurs through the formation and growth of silicate fibrils from individual cement particles. Concrete is produced through the judicious inclusion of aggregate materials, while waste fixation is achieved by mixing cement with the wet waste slurry.

Various additives have been developed to improve the waste immobilization properties of cement but these are mostly proprietary chemical formulations. The high pH of cement is particularly effective for immobilization of metals through the formation of insoluble hydroxides. Ideally, metals may be incorporated directly into the crystalline structure of the emerging cement minerals. The ability of these stablilization techniques to immobilize organic contaminants is at best uncertain. Some waste components such as sulphides, asbestos, latex, and plastic may provide increased structural stability to the matrix.

The permeability of cement stabilized products is reasonably low, while the structural stability of the matrix is relatively high. Surface sealing of the stabilized matrix can further reduce potential waste leaching.

Generally, the process technology is not significantly more sophisticated than normal concrete batching. This feature, combined with the widespread availability of the primary reagent (cement), makes this process relatively easy to implement. Waste preparation is generally minimal since entrained water can be utilized for the water of hydration and the cement is tolerant of many acids and oxidizing agents.

Many chemical components can interfere with matrix solidification. These include: various organic compounds, silt, clay, lignite, soluble salts of manganese, tin, zinc, copper and lead, and sodium salts of arsenate, borate, phosphate, iodate,and sulphate. High sulphate wastes require the use of special low aluminate cement to avoid the formation of calcium sulpho-aluminate hydrate which swells and causes eventually spalling.

Although solidification processes can improve the physical properties of residues, they increase the mass and the bulk of residue for disposal. This has a negative impact upon landfill capacity.

Solidified wastes must be protected from weathering. For example, freeze-thaw cracking, resulting from moisture entering cracks, can eventually destroy the matrix integrity and expose waste materials to leaching. Acidic solutions are capable of leaching some contaminants out of cement-stabilized materials and thus selection of disposal means must account for such possibilities. Additionally, the alkalinity of cement can, in some cases, give rise to noxious gas released from wastes. For example, wastes containing ammonium salts will release ammonia gas upon the addition of cement.

Advantages and disadvantages of cement-based processes have been summarized as follows (U.S. Army Engineer Waterways Experiment Station 1980).

Advantages

1. Cement materials are widely available and relatively inexpensive.
2. Cement mixing and handling is widely practiced and the equipment is commonplace. Specialized labor is not required.
3. Extensive drying or dewatering of waste is not required because cement mixtures require water. The amount of cement added can be adapted to a wide range of water content in the waste.
4. Cement stabilization is very "tolerant" of chemical variation. The natural alkalinity of the cement used can neutralize acids. Cement is not affected by strong oxidizers such as nitrates or chlorates.

Pretreatment is required only for materials that retard the setting reactions of cement.

5. Leaching characteristics can be improved, where necessary, by coating the resulting product with sealant.
6. Variation in the amount of cement used can produce a stabilized product with very high-bearing capacities which can function as good sub-grade and sub-foundation material

Disadvantages

1. Relatively large amounts of cement are required for most waste applications. This may be partially offset by the low cost of material. However, the weight and volume of the final product is normally about double that of other solidification processes.
2. Uncoated cement-solidified waste products may require a well-designed landfill for burial. Experience in radioactive waste disposal indicates that some wastes are leached from concrete, especially by mildly acidic leaching solutions.
3. Extensive pretreatment, or higher cost cement types or additives may be necessary for wastes containing large amounts of impurities such as borates and sulphates which affect the setting and curing of the waste-concrete.
4. The alkalinity of cement will cause ammonium ion in wastes to be released as ammonia gas.
5. Cement, despite its low cost, consumes considerable energy in its manufacture.

5.2.2 Pozzolanic Processes

Pozzolanic processes are based upon the reaction of lime and siliceous materials such as fly ash, pulverized blast furnace slag, or cement kiln dust. As such, these processes are similar to portland cement processes but have the added advantage of utililzing common waste materials as primary matrix components. The general comments addressed to the cement processes essentially apply to pozzolanic processes as well.

This type of process was by far the most commonly used stabilization process encountered at North American sites visited during the survey. Generally, cement kiln dust was the fixation material used.

The range of mixing ratios employed by various facilities was from less than 0.5 t kiln dust/t of residue up to a maximum of 2 to 3 t kiln dust/t of residue for waste water (Rollins Deer Park site visit, 1982; CWM Port Arthur site visit, 1982; BFI Lake Charles site visit, 1982; BFI Livingston site visit, 1982; Rollins Baton Rouge site visit, 1982; CWM Emelle site visit, 1982).

Advantages and disadvantages of this process have been summarized as follows (U.S. Army Engineer Waterways Experiment Station 1980).

Advantages

1. The materials can be very low in costs and widely available. Local spot markets have pushed prices up where demand has been heavy.
2. Little specialized equipment is required for processing since lime is commonly used to neutralize other wastes streams.
3. The chemistry of lime-pozzolanic reactions is relatively well known.
4. Extensive dewatering is not necessary because water is required in the setting reaction. However, material requirements will become high for very low solids wastes.

Disadvantages

1. The final product is heavier and bulkier than the unstabilized residue, thereby requiring more landfill volume. Swell factors on the order of 1.5:1 (volume after/volume before) were reported.

2. These solids still have considerable potential to leach water soluble constituents.
3. The alkalinity of these materials will also react with ammonium ions.

5.2.3 Thermoplastic Processes

These processes use organic agents which are plastic at high temperatures yet solid at ambient temperatures. Materials such as bitumen, paraffin, and polyethylene qualify.

The high costs of the fixation materials and the energy input inherent in heating and mixing make this process feasible only for small residue quantities.

Advantages and disadvantages of this process have been summarized as follows (U.S. Army Engineer Waterways Experiment Station 1980).

Advantages

1. The leach loss rates are significantly lower than those observed with cement-based systems.
2. By disposing of the wastes in a dry condition, the overall volume of the waste is greatly reduced. This, however, implies prior dewatering has been achieved.
3. Most thermoplastic matrix materials are very resistant to attack by aqueous solutions. Microbial degradation is minimal.
4. Most thermoplastic matrix materials adhere well to many residue materials.
5. Materials embedded in a thermoplastic matrix can be reclaimed by reheating the matrix.

Disadvantages

1. Expensive, complicated equipment is necessary for processing. This, in turn, requires specialized labor.
2. These systems cannot be used with materials that decompose at high temperatures, especially citrates and certain types of plastics.

3. Thermoplastic materials at high temperatures pose a fire risk.
4. Heating of wastes can release volatile pollutants from the wastes.
5. Only dry materials can be successfully processed. Incorporating wet wastes greatly increases leaching potential.
6. The incorporation of tetraborates or iron and aluminum salts in bitumen matrices causes premature hardening. This can clog and damage mixing equipment.

6. RESIDUE DISPOSAL

6.1 DISPOSAL CONCERNS

Chapters 2 and 4 have documented the existence of residues which will require some form of ultimate disposal. Since these residues cannot be destroyed, some form of disposal option must be found which can accommodate their existence without allowing significant environmental degradation. Every available option will pose some concern. Valid concerns should be clearly identified in order that relevant technical factors can be identified.

6.1.1 Landfill Disposal

Landfill disposal raises many concerns because of past malpractice in uncontrolled dumping of hazardous wastes. However, consideration of disposal concerns for residues from suitable treatment processes will focus on a narrower subset of valid concerns. These will be considered in two major categories: operational factors and ongoing/long-term factors.

6.1.1.1 Operational phase concerns. The major concerns associated with the operational phases of landfill disposal are fugitive air emissions, accidents (fires, explosions), and noise emissions. As operational concerns, these require operational solutions.

Fugitive odorous emissions would only be a problem if landfilling of organic liquids is contemplated. However, such a practice would not be consistent with the concept of landfilling only treatment residues since organic wastes should normally be incinerated. There is ample experience from other jurisidictions to justify a ban on landfill of volatile organic wastes. As an operational concept, the perception of odours sufficiently strong to create offsite odour problems provides an adequate basis to refuse landfill disposal for the offending batch of residue until subjected to further treatment. If such operational measures are implemented, fugitive emissions of odourous compounds should not be a problem.

Stabilization processes will likely use powdered reagents (like portland cement or kiln dust). Such fine powders will cause a blowing dust problem prior to incorporation into the waste unless specific precautions are taken. Specific measures will depend on the technology selected but there are no technological barriers to solving this problem. Generally, some form of containment for mixing pits would be appropriate.

Accidents in the form of fires or explosions should only be possible if flammable or explosive wastes are allowed to be landfilled, a practice which would clearly be unwise. Therefore, banning landfill of violently reactive materials should result in the avoidance of such problems provided that adequate operational controls are used. These controls would primarily consist of cross-checking waste characteristics before acceptance and also before disposal.

Noise emissions will be unavoidable because of the need for heavy equipment to operate in the excavation, filling, and compaction of landfills. However, the noise levels need not be any more significant than those associated with similar industrial activities. Adequate buffer zones between the noise generators and the nearest offsite receptor should eliminate any significant problem.

6.1.1.3 Long-term concerns. Major concerns associated with ongoing/long term factors are somewhat more difficult in general. Provided that future incompatible uses of the site are prevented, the major long term concerns relate to potential surface or groundwater contamination. Such problems can only arise if leachate (liquid contaminated by dissolving soluble constituents from the residue) is both allowed to be generated and allowed to escape from the controlled environment to contact surface or groundwater resources.

Leachate generation arises if too much liquid is allowed to contact the residues. Circumstances permitting such contact include: allowing liquid wastes to be landfilled; allowing surface water runoff to enter the landfill; or if rainfall at the landfill is significant, allowing percolation to contact the residues. The first condition can be eliminated by not allowing liquid wastes to be landfilled. The second requires diversion of surface water around the landfill cell. The third depends on providing an impermeable cap covered with topsoil and revegetated with shallow root species to prevent penetration of rainfall into the landfill cell.

Unfortunately, caps have been reported to fail for several reasons, including (Lutton, 1980):

1. erosion of the soil layer;
2. excessive root penetration by the vegetation;
3. penetration by burrowing animals;
4. sunlight dessication and cracking of soils or UV degradation of membrane liners;
5. differential subsidence due to landfill compaction;
6. various disruptive human activities; and
7. freeze/thaw soil cracking.

Even though some of these problems can be avoided, it would be wise, given the choice, to select landfill sites with as low rainfall and as high net evaporation as possible. Locations which experience high intensity storms, even if infrequently, should also be avoided. As well, the use of solidification/stabilization technologies should dramatically reduce leachate generation potential.

Although leachate need not be generated in hazardous waste landfills, if leachate is formed it certainly demonstrates the characteristics necessary to contaminate surface or groundwater. Table 10 shows average leachate characteristics for the GSB Gallenbach secure landfill (Proctor & Redfern Group 1982b). Table 11 shows average and extreme leachate characteristics for the ZVSMM Schwabach secure landfill (ZVSMM site visit, 1981). In both cases, an estimated 10 000 t/a of leachate was collected for treatment. Both these landfills are associated with integrated treatment facilities incorporating rotary kiln incineration and various

Table 10. Average leachate characteristics GSB Gallenbach secure landfill.[a]

Parameters (mg/L except for pH)	1977	1978	1979	1980
pH	7.0	7.4	7.2	7.4
BOD	2720	3000	4000	4650
COD	3000	3500	9000	12000
TOC	1600	1900	4000	3400
chromium (Cr)	0.4	0.7	0.5	0.2
copper (Cu)	0.3	0.3	0.4	0.3
nickel (Ni)	4.1	5.2	3.6	4.4
zinc (Zn)	2.3	0.5	0.6	0.4
cadmium (Cd)	0.2	0.1	0.2	0.2
iron (Fe)	12	4	4	2.1
tin (Sn)	2.3	8	4.4	3.4
lead (Pb)	0.6	1.0	1.2	1.1
phenol	2.1	7.3	1.0	1.0
chloride	15 000	26 000	37 000	40 000
sulphate	2100	3400	8300	3300

[a] Source: Proctor & Redfern Group (1982b)

Table 11. Leachate characteristics ZVSMM Schwabach secure landfill.[a]

Parameters (mg/L except for pH)	Average	Minimum	Maximum
pH	9.2	8.2	10.2
COD	9128	3066	15 800
chromium (Cr)	0.87	0.12	6.00
copper (Cu)	2.58	0.36	79.6
nickel (Ni)	5.12	1.85	8.2
zinc (Zn)	1.37	0.26	3.8
cadmium (Cd)	0.08	0.01	0.16
iron (Fe)	2.58	1.24	5.20
vanadium	89.6	42.3	164
phenol	38.6	4.0	145
chloride	3784	800	7240
sulphate	24 016	12 098	30 260
cyanide	2.8	0	5.0

[a] Source: ZVSMM site visit 1981

physical/chemical treatment processes. Yet, the landfill leachates exhibit a very high organic content. In the case of the GSB site, it is not certain to what extent the values reported may be influenced by an adjacent sanitary landfill. Neither of these sites employs any solidification/stabilization technology which might reduce the extent of leachate contamination by reducing residue permeability.

In addition to avoiding leachate generation, the landfill can be designed to contain, to a large degree, leachate which may be generated. This will involve both the use of an impermeable liner which may be provided, in part, by site geological conditions, and the provision of adequate cell drainage. The latter will allow leachate to be collected and removed from the landfill cell before it can significantly penetrate the liner and ultimately contaminate any groundwater.

The ongoing/long term concerns can be addressed by considering suitable technical factors and a rational framework for their uses.

6.1.2 Land Treatment

Land treatment systems are being actively considered for a variety of hazardous wastes. This technology was encountered at 5 of the 32 commerical offsite facilities surveyed in the U.S. Land treatment offers the prospect of detoxifying and degrading hazardous wastes through a combination of chemical, physical, and biological processes in the soil. Concerns associated with such systems may be grouped into soil/waste interactions, water quality, air quality, health/safety, and aesthetics (Phung et al. 1978).

Soil/waste interactions of concern include the land application of organic compounds which are not degradable, leading to accumulation of resistant compounds in the soil. Degradable organics may be applied at excessive rates, leading to the development of anaerobic conditions. Toxic metals cannot be degraded by soil systems and must necessarily accumulate. Inorganic salts can also accumulate and adversely affect soil properties and productivity.

Water quality concerns relate to constituents of the wastes which are not consumed by plants, degraded by organisms, or fixed by the soil to an adequate degree. These constituents will be available to leach from the soil and contaminate groundwater or they may be available for surface runoff. Soluble anions will be particularly prone to leaching in soil systems because of the limited anion exchange potential of soils. Light hydrocarbons are also notorious for rapid migration through soil systems.

Air quality considerations primarily relate to potential odour problems. These may arise because of odourous constituents in the waste applied or because hydraulic or organic loading rates saturate the soil causing anaerobic conditions. Such conditions in turn promote odour.

Health and safety concerns primarily relate to site personnel who may face noxious conditions of dust or vapor emission from waste application or land cultivation. These conditions would pose health problems for offsite populations only if the facility was poorly sited.

Aesthetics of land treatment systems can pose difficulties unless care is directed toward managing odour and unsightliness. Effective cropping can assist aesthetics in situations where vegetation can be sustained.

In general, land treatment systems are not suitable in high precipitation regions. In the case of Alberta, facility siting to meet the demands of the landfill will also be favourable for location of a land treatment system. However, alternate problems arising from Alberta's winter climate may preclude some of the land treatment options currently being pursued in warmer climates.

6.1.3 Deep Well Injection

This form of residual disposal is limited to liquids which can be injected into permeable underground formations without causing formation plugging. Thus, solid and sludge residuals may not be disposed in this manner.

This disposal option is widely practiced in Alberta for refinery and petrochemical plant wastewaters. Reid Crowther (1980) estimated annual waste disposal of approximately 2.75 x 10^6 m^3/a and listed 12 operating industrial disposal wells.

The main concerns with this disposal option relate to the possible degradation of usable groundwater resources. In particular, there would be uncertainty associated with disposal of untreated, highly toxic wastes in remote underground formations where future tracking or retrieval is not possible.

6.1.3.1 General groundwater degradation. Dealing with this concern is primarily dependent upon assuring:

1. good site selection based upon geohydrologic factors;
2. good well completion to plug off permeable zones above the disposal zone; and
3. good operation practices to avoid system failure.

Failures in deep well injection systems have arisen because of poor site selection or poor operating practice. A Sarnia area disposal well for caustic and phenolic refinery wastes at a depth of only 200 to 260 m was blamed for surface contamination via unplugged abandoned wells (Simpson 1976, cited in Freeze and Cherry 1979). Aust (1981), also reported a failure for a shallow (60 m) phenolic disposal well in Germany, although unplugged wells were not implicated in this case.

In fact, there may be more than 1 million unplugged, unlocated wells in North America which may pose the greatest hazard to the widespread use of deep well injection for hazardous waste disposal (van Everdingen and Freeze 1971, cited in Freeze and Cherry 1979). Alberta may be fortunate in having a relatively low proportion of such undocumented wells since the majority of oil and gas drilling activities have taken place since the creation of the Oil and Gas Conservation Board (now ERCB). This agency requires extensive documentation of well location and abandonment procedures.

Piper (1969) reported upon a 3600 m disposal well at Rocky Mountain Arsenal in Denver which was blamed for causing a series of mild earthquakes with magnitudes ranging from 0.5 to 5.3 (Richter scale). Vecchioli (1981) reported on potential problems developing for two industrial deep wells in Florida. One, injecting hot (75 to 93°C), acidic (pH 2.6 to 4.5) wastewaters, has exhibited upward migration of the injected waste, through the confining bed. Another, injecting acidic (pH 1) waste has developed a cavity estimated at 30.5 m high and 7 m out from the injection well base. This situation raises concern about possible collapse of the overlying confining bed with loss of the well and potential upward contamination flow.

Reeder et al. (1977) extensively reviewed deep well disposal practice for hazardous wastes in the U.S. They included 11 case studies in their assessment, with four (including some mentioned above) indicating problems. The problems were judged to be the result of poor location or poor operating practice.

6.1.3.2 Toxic waste disposal. Concerns about toxic waste disposal by deep well injection are similar to those discussed above, except the consequences may be substantially more severe. Contamination of groundwater with salts or taste- and odour-causing compounds might render the groundwater unpalatable and useless. However, contamination of a groundwater supply with trace concentrations of carcinogens or mutagens might well go undetected for some time unless there were also some warning of the problem from either taste or odour. Consequently, some jurisdictions regard deep well disposal of such wastes as unwise. Aust (1981) described the rejection of a disposal well for chlorinated hydrocarbons near Landau, Germany, despite allowing the existence of 31 other operating industrial disposal wells injecting from 100 to 70 000 m^3/a. The reasons given for rejection included:

1. the health hazard associated with chlorinated hydrocarbons;
2. no evidence of "absolute" confinement;
3. impossibility of monitoring waste migration;
4. seismic risk in the region;

5. dense population in the disposal area; and
6. possible negative impacts on the future use of a thermal anomaly.

6.2 TECHNICAL FACTORS

6.2.1 Landfill

Analysis of concerns about landfill disposal suggests that surface and groundwater contamination by leachate poses the most difficult technical problem. Fortunately, there are several technical approaches which can be applied to minimize the significance of leachate as a disposal concern.

6.2.1.1 Leachate migration. Fluid flow in porous materials has been found to be governed by the empirical Darcy's Law which states, for a generalized system as depicted in Figure 9, that:

$$Q = -K \frac{\Delta h}{\Delta \ell} A \qquad (1)$$

or in differential form:

$$Q = -K \frac{dh}{d\ell} A \qquad (2)$$

where:

Q = flow in m^3/s
A = cross sectional area of flow element in m^2
$\frac{dh}{d\ell}$ = hydraulic gradient based upon differential head over the length of the flow path, dimensionless
K = hydraulic conductivity in m/s.

A thorough development of this concept is provided by Freeze and Cherry (1979). Further evaluation will show that:

$$K = \frac{k \rho g}{\mu}$$

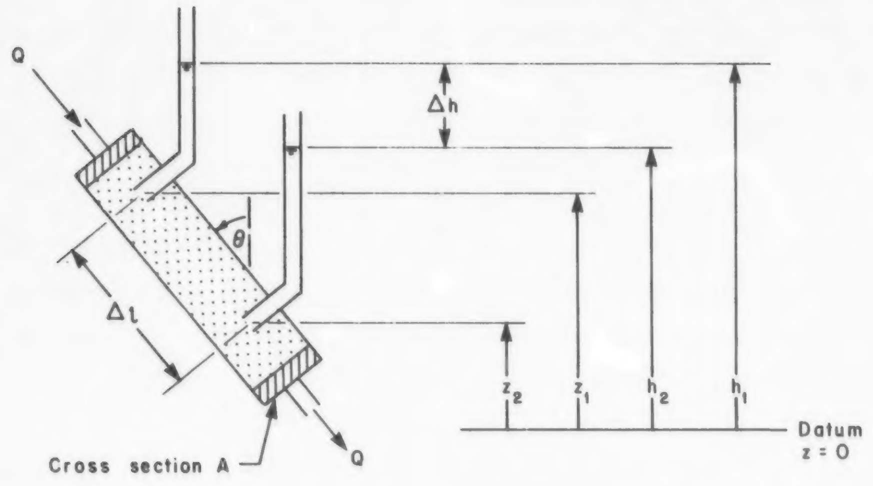

Q
Δh
θ
Δl
z_2
z_1
h_2
h_1
Datum
$z = 0$
Cross section A
Q

Figure 9. Definition sketch for Darcy's Law (Freeze and Cherry 1979).

where:

k = specific or intrinsic permeability in m^2
ρ = fluid density in kg/m^3
g = gravitational acceleration 9.8 m/s^2
μ = dynamic viscosity, kg/m.s

In practice, specific permeability is a very small number and is usually expressed in cm^2. The literature on waste containment has been considerably confused by the use of the term "permeability" to refer to hydraulic conductivity, as defined herein. For example, liner specifications are usually given in terms of a "permeability" in cm/s and a corresponding liner thickness. Throughout this report, hydraulic conductivity will be used, as defined above, in place of the unqualified term "permeability". In so doing, we are presuming that the fluid of interest (leachate) is essentially water in terms of its fluid density and dynamic viscosity. Although we know this to be untrue as the leachate becomes increasingly contaminated, the differences involved are small relative to the 13 orders of magnitude over which hydraulic conductivity is relevant (Freeze and Cherry 1979). Figure 10 shows that twofold differences in this parameter are of little consequence, particularly considering the large error and uncertainty involved in measuring hydraulic conductivity. This conclusion must be differentiated from the very different issue of the effect which leachate contaminants may have in modifying soil hydraulic conductivity. The latter issue will be addressed later in this report.

The relationship provided by Darcy's Law allows prediction of the flow per unit area as a function the hydraulic conductivity, K and the hydraulic gradient $dh/d\ell$ as:

$$Q/A = -K \frac{dh}{d\ell} \qquad (4)$$

This relationship shows that unless the hydraulic conductivity is zero, there will always be some flow in response to a hydraulic head. Since it is not possible to have a zero value for

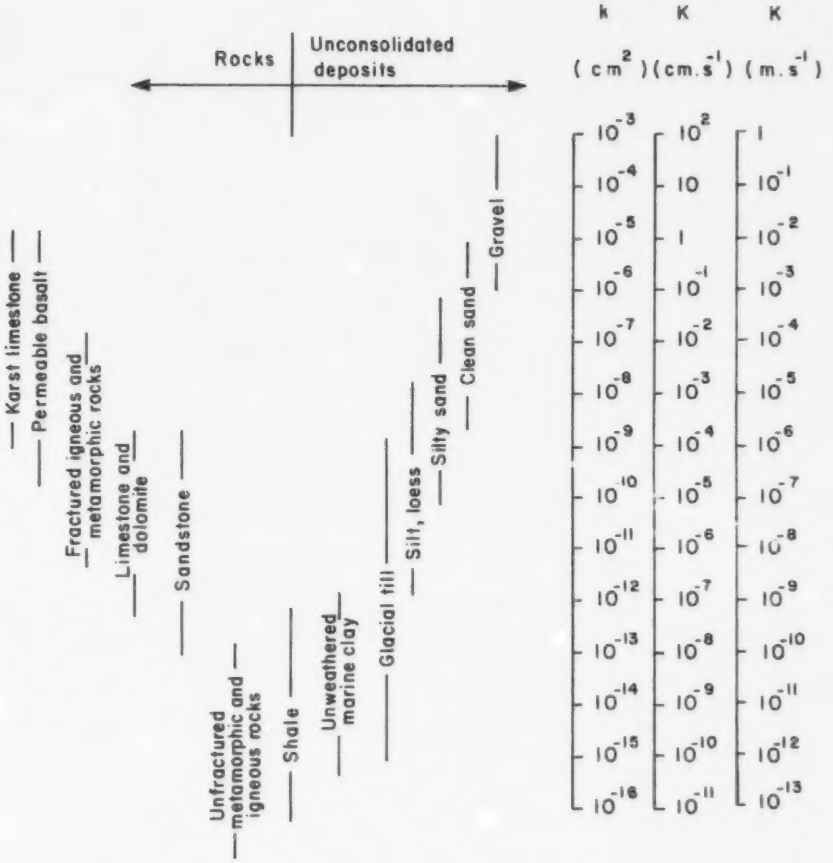


Figure 10. Practical range for hydraulic conductivity (Freeze and Cherry 1979).

hydraulic conductivity and the hydraulic gradient is essentially 1 for vertical flow, some flow is inevitable. In practice, if the soil is not saturated with liquid, the hydraulic gradient may be less than 1.0 due to capillary effects in the unsaturated soil mass. Analysis of flow in unsaturated soils becomes complex but the details are not essential for the problem at hand. It will suffice to recognize that some downward flow is inevitable regardless of the liner system employed. However, the rate of flow may be insignificantly small and need not pose a significant problem if several logical steps are taken.

6.2.1.2 Control leachate generation. In order for leachate to pass through a landfill liner it must first be generated. There are several reasonable steps which can be taken to minimize leachate generation. These include the following procedures:

1. Do not allow free liquids in the landfill.
2. Solidify all moisture containing wastes to chemically bind the moisture to the solidified waste mass.
3. Site the landfill in a zone of minimum precipitation and maximum net evaporation. Analysis of these factors must account for infrequent storm events since precipitation falling on an open cell will be sealed into that cell by normal operations.
4. Prevent significant quantities of snow from entering the landfill during winter operations and divert surface runoff away from operating areas.
5. Minimize the cell areas exposed to precipitation at any given time and provide means for collection and removal of excess precipitation from exposed cells.
6. Seal and reclaim the site to prevent precipitation from gaining access to completed cells.

Such procedures cannot be solely relied upon to prevent leachate generation for the reasons noted in section 6.1.1. However, effective cell capping can certainly contribute to reducing the potential for leachate generation. Detailed consideration of landfill capping procedures was provided by Lutton (1980).

6.2.1.3 Leachate drainage and collection. Even with all the foregoing steps to prevent leachate generation, it is wise to also provide means to efficiently drain and collect any leachate which may be unavoidably generated. This is a prudent measure since retroactive installation of a leachate collection system into an operating or completed cell would be extremely expensive and undoubtedly ineffective.

Effective leachate collection must use the concept of hydraulic permeability to promote flow to drains and a collection system. The design of an effective drainage system for a landfill is not a trivial exercise and involves more than spreading some sand on the bottom of the landfill cell. A rigorous site specific design by a Professional Engineer experienced in drainage work must be performed for each cell.

An effective leachate collection system will function initially to monitor the effectiveness of the measures used to reduce leachate generation. If the measures are found to be ineffective, this feedback can provide the impetus to investigate and improve upon them. It can also provide the means to reduce the quantity of standing leachate at the base of the landfill to levels which do not significantly challenge the soil assimilation capacity of the site. This concept will be elaborated in section 6.2.1.4.

In summary, Darcy's Law, as embodied by equation 4, predicts flow per unit area, Q/A as the product of hydraulic conductivity, K and hydraulic gradient $dh/d\ell$. Effective control of leachate generation and collection of leachate establishes a ceiling for Q/A by limiting the maximum Q available. Furthermore, these measures will reduce the hydraulic gradient by reducing or essentially eliminating standing leachate at the bottom of the cell.

6.2.1.4 Cell liner. The previous section illustrated how Q/A could be limited by leachate collection. In addition to these measures, Q/A can be controlled by reducing the value of the hydraulic conductivity, K. This can be achieved by:

1. selecting a site with low hydraulic conductivity provided by the in situ geology;
2. engineering a liner with naturally impermeable materials such as clay;
3. engineering a liner with synthetic impermeable liners such as plastic membranes or bitumen; or
4. some combination of the above.

Technical details of available liner systems have been thoroughly reviewed by Matrecon, Inc. (1980).

It is worth repeating that, given a source of liquid and a hydraulic head (which is assured for downward migration unless the base of the cell is at or below the natural groundwater table), some flow is inevitable. Hence, the efforts expended in limiting the earlier factors are worthwhile. This point should also be focussed on the inevitability of some leakage from surface impoundments and lagoons, which depend solely upon soil liners. Synthetic liners can approach total containment provided their integrity is not ruptured by physical or chemical attack. At present, the integrity of synthetic liners cannot be guaranteed for long term application because experimental simulation of long term exposure is not possible.

Modifications to original liner hydraulic conductivity are possible due to waste interactions with liners. Research on liner/waste interactions has demonstrated the potential for many significant problems with both natural clay and synthetic membrane liners (Anderson 1982; Anderson et al. 1982; Anderson and Brown 1981; Brown and Anderson 1980; Green et al. 1981; Haxo 1976a, 1976b, 1980, 1981, 1982).

Most of these studies highlight the need to evaluate the specific interaction between a given waste and the liner. The need for evaluation leads to two approaches. First, wastes should be segregated to different cells on the basis of liner reaction potential as well as on the basis of interaction with other wastes. Present knowledge of liner interactions does not provide guidance much beyond segregation of acid and alkaline wastes. Stabilization of all wastes could eliminate this requirement. Second, subsamples of major residues should be retained in long-term experimental contact with pilot scale samples of the liner system to allow predictive assessment of any long-term adverse effects.

6.2.1.5 Site assimilation capacity. Total containment of wastes within a landfill may be no more economically achievable than 100% BOD removal in sewage treatment. Therefore, means are required to deal with the uncontained fraction. The analogy with sewage treatment and disposal provides a concept for consideration. Some measureable level of treated effluent discharge to rivers is commonly accepted, provided the discharge levels do not exceed the ability of the river to sustain high water quality for valid defined uses. There has been ample research performed to demonstrate the capability of soils to attenuate toxic materials (Alesii 1976; Chou et al. 1981; Davidson et al. 1980; Dragun and Helling 1981; Fuller 1977, 1978; Fuller et al. 1980; Griffin 1976; Griffin and Chian 1980; Korte 1976; Rovers 1976). Hence, this reality should not be ignored in developing realistic landfill management strategies.

Provided all the foregoing measures to reduce leachate generation and movement are implemented, the actual quality of leachate which might be able to migrate from the cell should likely be undetectable. The assimilation capacity of the natural soil should be able to rapidly remove these trace contaminants well within a zone of influence which should be part of the waste management facility. The suitability of this final buffer of protection for the surrounding environment will be largely determined by the suitability of the site's geological conditions. The extent of this buffer zone must be large enough, providing a large factor of safety, to protect any potentially usable groundwater resources.

6.2.1.6 Gas generation and collection. Provided the landfill was receiving only residues processed by the technologies described in Chapter 4 (except biological treatment sludges, which are not anticipated for Alberta), generation of landfill gases would not be expected. On the other hand, the very high COD values reported for leachate from GSB and ZVSMM (Tables 10 and 11) would certainly be capable of sustaining methane-forming anaerobic bacteria. Both these sites employed most of the technologies being considered for Alberta and presumably their residue disposal to landfill should reflect such use. The notable exception was the lack of any solidification/stabilization prior to landfilling at these sites. Based on information available at this time, a significant gas generation problem for the Alberta landfill would seem unlikely. However, this point should be explicitly reviewed before making a final commitment to not providing gas collection in the landfill. Perhaps running a small scale monitoring test on the first set of cells would be a reasonable compromise if more definitive information cannot be found.

6.2.2 Land Treatment

Interest in the potential of land treatment has resulted in considerable research activity and, recently, two detailed manuals have been published on land treatment of industrial wastes (Overcash and Pal 1979; Brown and Devel 1980). They provided literature reviews and recommended considerations based upon specific waste parameters. These resource documents provide an excellent starting point for developing a land treatment system, but specific waste, soil, and climate characteristics will require onsite experimentation before a fully satisfactory treatment system can be developed.

Some of the many technical factors which must ultimately be addressed and resolved in designing a land treatment system are listed in Table 12 (Willson et al. 1982). Careful consideration of these factors when implementing a pilot scheme should insure that valid operational criteria can be developed for the specific site

Table 12. Characteristics of industrial wastes and factors affecting their safe and effective detoxification, degradation, and inactivation in land treatment systems.[a]

Hazardous Waste	Waste Factors	Soil Factors	Management Factors
Characteristics	Chemical	Soil Environment	Application Scheduling
ignitability	pH	moisture	loading rate
corrosivity	salinity	temperature	mode/method
reactivity	acidity	pH	time/frequency
toxicity	alkalinity	Eh	monitoring
radioactivity	BOD	aeration	
infectivity	COD	available nutrients	
phytotoxicity	C:N ratio	C:N ratio	
teratogenicity	heavy metals	soil texture	
& mutagenicity	toxic organics	soil structure	
	plant nutrients	crop residues	
		soil organic matter	
		soil microflora	
	Physical	Site Selection	Agronomic
	solid	soil type	tillage
	liquid	slope	cropping
	slurry	compaction	climate
	sludge	drainage	compost
	particle size	groundwater depth	
	volatility	wind direction	
	Microbiological		
	indigenous microflora		

[a] Source: Willson et al. 1982

and waste profile at hand. Ultimately, site specific loading criteria, such as those proposed for metals in Table 13 (Brown and Devel 1980) can be developed. These should assure safe long-term operating conditions for the system, but ongoing monitoring will be necessary to insure satisfactory performance.

6.2.3 Deep Well Injection

Reeder et al. (1977) listed criteria for determining the feasibility of a well site within a geologically suitable area. These are:

1. uniformity of geological formation;
2. large areal extent;
3. substantial thickness;
4. high porosity and permeability;
5. low existing pressure;
6. formation water is saline;
7. adequate separation from freshwater horizons by aquicludes;
8. absence of poorly plugged wells nearby; and
9. compatibility between the formation, formation fluids, and the injected waste.

Once a suitable site has been located, the well must be drilled and completed according to the best engineering practice. This technology has been well documented by Warner and Lehr (1981).

Assurance of safe operation should be provided by adequate monitoring of both the facilities and the general receiving aquifer (Vecchioli 1981). Concerns with the well facilities relate to the possibilities of casing failure, grout or packer deterioration, aquifer pore clogging, and severe dissolution of formation rock. These factors can be detected by continuously monitoring the injection pressure, rate and volume of injection, annulus pressure, and the physical/chemical characteristics of the injection fluids. Any sudden change or irregularity in monitored parameters provides a warning that problems may be arising (Smith 1979). Most problems caused by the wastes can be avoided by preinjection treatment of the

Table 13. Proposed cumulative soil loading limits for selected metals.[a]

Metal	ppm	Loading Limit in Soil kg/ha-15 cm
Arsenic	500	1120
Cobalt	500	1120
Chromium	1000	2240
Nickel	100	220
Lead	1000	2240
Zinc	500	1120

[a] Source: Brown and Devel, 1980

waste to insure the absence of unfavourable reactions in the formation. Pre-treatment may include neutralization, precipitation, or oxidation/reduction and should include filtration to <1 μ particle size.

Monitoring of the aquifer should have the following objectives (Vecchiolo 1981):

1. determination of the aquifer pressure buildup distribution;
2. location of the waste and evaluation of the rate and manner of movement;
3. assessment of changes in waste characteristics;
4. detection of any upward waste migration; and
5. displacement of saltwater/freshwater interfaces if they exist in the formation.

Figure 11 depicts a schematic monitoring system to provide such information.

A final factor which warrants attention is the handling of wastes prior to injection. The best disposal well in the world will be of little value in protecting groundwater resources if surface impoundments and transfer lines leak. There are countless documented cases of groundwater contamination from industrial impoundments both lined and unlined. Hence, corrosion-resistant tankage, together with suitable shallow leak detection monitoring, should be provided in preference to open impoundments.

6.3 REGULATORY CONSIDERATIONS

The regulation of hazardous waste treatment and disposal has received increasing attention by all industrialized nations in recent years. Most European countries currently have some form of general legislation governing chemical waste disposal (WHO 1982) but regulatory details are usually site specific. Comprehensive regulatory philosophies applicable to various types of disposal methods are rarely specified in any detail. In the United States, on the other hand, the Resource Conservation and Recovery Act of 1976 (RCRA) has spawned a regulatory process which has filled

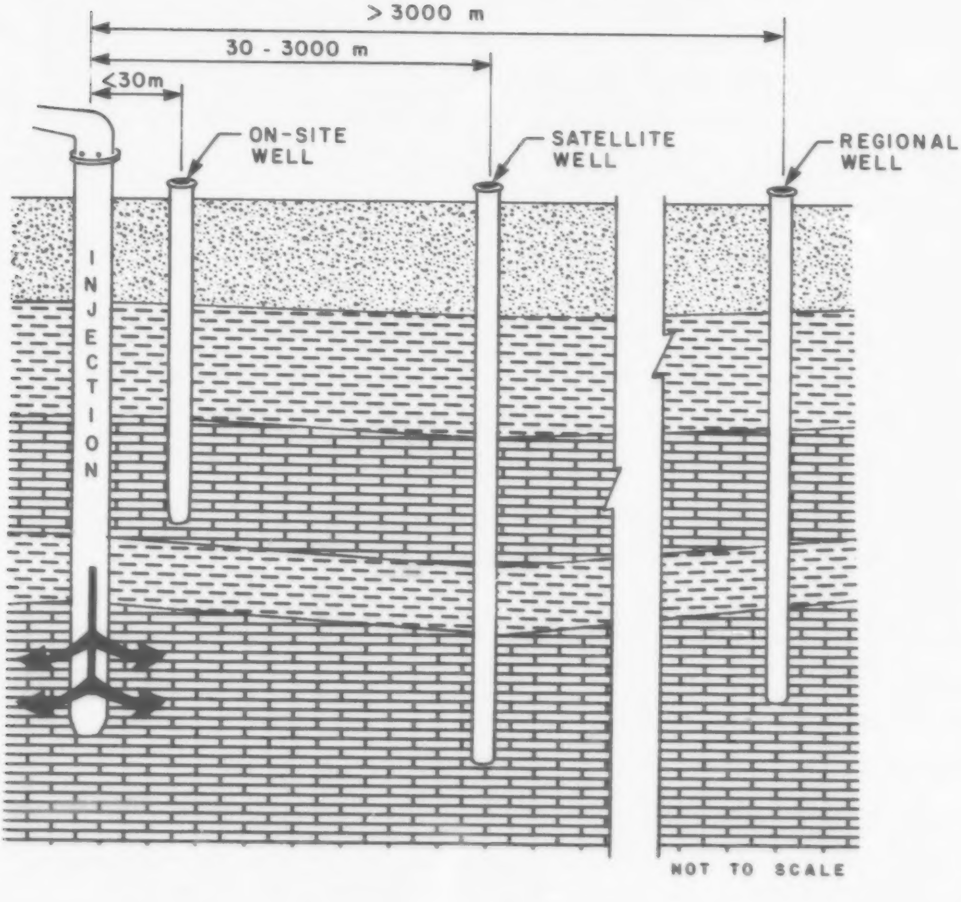

> 3000 m
30 - 3000 m
<30m
ON-SITE WELL
SATELLITE WELL
REGIONAL WELL
INJECTION
NOT TO SCALE

Figure 11. Monitoring scheme for idealized deep well disposal system (Vecchioli 1981).

several hundred pages with regulatory proposals. The sheer volume of these regulatory specifications has generated considerable negative commentary. However, this regulatory effort has been largely responsible for much of the research conducted on hazardous waste disposal. Furthermore, the concepts proposed in subsequent stages have been subjected to considerably more technical feedback than any other regulatory models which could be studied. In view of the massive effort which has gone into formulating and modifying regulatory proposals under RCRA, it would be unwise to develop regulatory details for Alberta without at least carefully reviewing the RCRA proposals.

Development of regulations for land disposal of hazardous wastes under RCRA has had a turbulent history. This is documented in the most recent proposals (U.S.EPA 1982). The U.S. Environmental Protection Agency (EPA) had intended to develop these regulations only by the fall of 1983, but a successful suit by the State of Illinois forced their issuance in 1982. Consequently, EPA acknowledged that the regulations, which took effect on 1983 January 26, are not as technically detailed as they would have wished.

The regulations apply to land storage, treatment, and disposal facilities including the landfill and land treatment options being considered by Alberta. They incorporate two sets of performance standards. One is a set of design and operating standards applicable to each operation unit. The second is a uniform set of groundwater monitoring requirements applicable to any of the units. The first set is intended to insure that operators minimize the formation and escape of leachate from their facilities. The second set is designed to insure that any groundwater contamination problems which might occur are detected early enough to allow corrective action before any significant threat to human health or environmental quality occurs. The regulations also address requirements for closure of facilities and post-closure care and monitoring.

In developing their regulatory approach, EPA considered up to five approaches at various times. These may be summarized as (U.S.EPA 1982):

1. Design and Operating Standards - Such standards would require installation of specific equipment or use of particular practices. An example is a liner specification such as 2 feet of clay with a permeability of 10^{-7} cm/sec.

2. Technical Performance Standards - Such standards establish an engineering objective and allow the permit applicant to develop a design or set of practices to achieve the objective. An example is a requirement to develop a run-off control system that can accommodate the water volume from a specified storm event (e.g., 24-hour, 25-year storm).

3. Containment Standards - Such a performance standard would require that the permittee keep waste or waste constituents within a certain area for a fixed period of time. An example is a liner standard requiring that the liner be able to contain waste for 100 years.

4. Environmental Performance Standards - Such standards specify limits (usually numerical) on levels of contamination that may be tolerated in the environment. An example is a ground-water quality standard for the groundwater below the facility.

5. Risk Assessment Standard - Such a standard would establish broad narrative criteria to guide the permit-issuing authority in doing a site-specific assessment of the risks associated with the facility and in developing permit conditions that reduce the risk to acceptable levels. An example is a standard which requires the permit applicant to demonstrate that there will be no significant risk of cancer resulting from the facility.

After considerable feedback and reevaluation, EPA sought to combine technical performance standards with environmental performance standards in the regulations. However, they acknowledged a need to rely on some design standards where the court-imposed time frame for issuing the regulations precluded the development of realistic performance standards.

Regulatory concepts applicable to landfill and land treatment will be considered in turn. The development of standards for underground injection of hazardous wastes has overlapping jurisdication with provisions of the Safe Drinking Water Act and this process has been continuing.

6.3.1 Landfill

Appendix 10.4 presents an extract of actual RCRA regulations (U.S.EPA 1982) applicable to landfills. Critical aspects relative to this discussion relate to the requirements for liners (and provision for waivers) and the tradeoff between groundwater monitoring and provision of a double liner.

These regulations require that all permitted hazardous waste landfills (subject to applications for waiver) shall install a liner to prevent the passage of leachate from the landfill during the operating life of the landfill. As described in the preamble, prevention of leachate passage can only be functionally achieved by a synthetic membrane liner in concert with an effective leachate collection and removal system. A compacted clay liner is specifically ruled out as adequate to meet the intention of this provision. There is provision for a waiver of this requirement, if the applicant can convince the Regional Adminstrator that "alternate design and operating practices together with location characteristics, will prevent the migration of any hazardous constituents [see sec. 264.93] into the groundwater or surface water at any future time." This provision places the onus on the operator to provide evidence of effective containment by some other means. In some cases, proving that argument may be less cost effective than simply implementing the liner/leachate collection system. EPA regards prevention of leachage passage during the operation of the landfill as technically feasible provided leachate generation is controlled and leachate is collected by measures such as those discussed in Section 6.3.1.2 of this report.

The second major issue is the allowance for a tradeoff between the specific requirements for ongoing groundwater quality monitoring (Appendix 10.5) and the alternative of constructing the landfill with a double liner providing a leak detection system. This provision would exempt the operator from the groundwater monitoring requirements until such time as there was evidence of leakage detected between the double liner.

6.3.2 Land Treatment

Appendix 10.6 presents the actual RCRA regulations (U.S.EPA 1982) applicable to land treatment. Critical aspects relative to this discussion relate to the requirements for a treatment demonstration and for unsaturated zone monitoring.

The approval of a land treatment scheme under these regulations is contingent upon demonstrating that the specific hazardous constituents in each waste can be completely degraded, transformed, or immobilized in the "treatment zone." This zone is defined as a region no more than 1.5 m deep and more than 1 m above the seasonable high water table. Essentially, land treatment is only regarded as suitable for wastes which can be detoxified or suitably bound by the soil.

The second major factor is the requirement for unsaturated zone monitoring. These requirements are in addition to the groundwater monitoring requirements (Appendix 10.5) which were also specified for landfills. Monitoring the unsaturated soil zone is regarded as an early warning system for the "unlined" land treatment system in lieu of the liner system required of landfills. The identification of hazardous constituents appearing in the unsaturated zone would not necessarily be regarded as a breach of the regulations. Rather, such an occurrence would require the operator to investigate the causes and propose improved procedures to eliminate the problem.

6.3.3. Deep Well Injection

The usual permit criteria required by American states which allow deep well disposal have been summarized by Smith (1979). These include the following factors:

1. Justification. As a general rule, a well will not be permitted if there are other ways of treating the waste(s). (Economics are not considered in making this decision.)
2. Selection of well site. Usually a site must be within the confines of the existing plant property.
3. A complete hydrologic assessment of the potable water (including mapping) within a minimum 4 km radius must be performed.
4. A complete geologic assessment of the chosen disposal zone, including isopach and structure maps, E-W and N-S cross-sections, and a map of surface features must be performed.
5. A detailed engineering design of the well construction, including appropriate drawings, must be prepared.
6. A complete chemical analysis of each waste stream, including volumes, must be supplied.
7. A description of the process(es) from which the waste(s) are generated (trade secrets may be protected) must be compiled.
8. A design of the surface facility for preconditioning the waste fluids before subsurface injection must be detailed.
9. An identification of every well ever drilled within 4 km of the proposed disposal well location, an establishment of each well, as assessment of present condition, and a determination of potential access from the disposal zone to the potable zones via the well must be compiled. Note: all wells that present a possible danger must be properly corrected before a permit will be issued.

10. Disposal-zone calculations that forecast fluid and pressure frontal movement away from the disposal wellbore with respect to time and cumulative volume injected must be performed.

General policy regarding deep well disposal of highly toxic wastes is divided between two groups. There are those who regard competent deep well disposal as a panacea for all liquid wastes and those who oppose deep well disposal of any toxic wastes. The relative merits of the two viewpoints can probably not be reconciled.

A rational approach to waste management could be based upon the concept of incremental risk. Most regulators accept that zero risk is unachievable. Likewise, deep well disposal proponents must acknowledge that there is greater than zero probability of a deep well injection system failing due to some human or material failure. Given these realities, the decisions concerning which wastes should be allowed for deep well disposal should be based upon the incremental risk consequences of disposal system failure rather than being solely based upon probability of failure.

Since Alberta is an oil and gas producing province, there is already significant risk of potable groundwater being contaminated by hydrocarbons or hydrogen sulphide. Such contamination would render the water supply unpalatable before long-term health effects could occur. On the other hand, failure of a disposal well handling pesticides or trace carcinogens by some improbable human or material failure could, in the worst case, have serious health consequences before being detected.

A concept of incremental risk, based upon the consequences of potable water contamination, would allow deep well injection of certain specific wastes. Those wastes which provide sensory (taste or odour) warning of contamination, before causing health effects, could be acceptable. However, those which could cause health effects at contaminant concentrations which do not provide adequate sensory warning of their presence, in water, would not be eligible for deep well disposal. There is a possible contingency, in the latter case which might make those wastes acceptable. A sensory marker, such as the mercaptans which are added to give natural gas an odour before distribution, may be a viable additive to make some wastes acceptable. However, implementation of a marker concept would depend upon demonstrating that the sensory marker would remain with the waste without any selective attenuation.

In the case of onsite deep well disposal at a centralized hazardous waste treatment facility, it should be feasible to limit deep well disposal to saline scrubber waters and other lightly contaminated wastes. In fact, the characteristics of final liquids requiring disposal may not justify the cost of a deep well installation. The potential for water re-use at the centralized facility should be exhausted before a final commitment to deep well disposal is made.

7. COSTS

The costs associated with ultimate residue disposal should be considered in the context of the total facility operation. A detailed analysis of hazardous waste treatment and disposal technology was performed by Hansen and Rishel (1980). Their findings are summarized in Table 14 for some of the technologies considered in Section 3. These data are presented in the form of life cycle average costs which included capital, operation and maintenance, and inflation factors relevant in 1980. Perhaps the most striking finding presented by Hansen and Rishel is the dramatic drop in cost per tonne for landfill versus incineration as the scale of operation expands in throughput. While this analysis would appear to suggest that incineration would be more attractive than landfill for a throughput of about 0.5 t/h, the practicality of an incinerator so small is open to question. Furthermore, the land disposal costs cited by Hansen and Rishel appear to be unreasonably high.

Perhaps a more reliable indicator of costs would be the rates currently charged for various types of treatment and disposal. Charges for various types of disposal at operating facilities surveyed in Europe are summarized in Table 15 and in North America in Table 16. While these data provide an interesting overview, the wide geographical and institutional differences preclude their direct translation to Alberta conditions.

A final approach to residue disposal cost evaluation may be derived from the economic analysis performed by the U.S.EPA (1982). They analysed the costs inherent in adopting their regulations on treatment and disposal facilities. Table 17 estimates the costs (US$) for a single synthetic liner, double liner (two synthetic), and double liner (synthetic/clay) for various landfills sized in waste load as t/a. The figures suggest a 1981 cost of about US$14 per t for a 60 000 t/a landfill which would correspond to the example given in Section 3.3. EPA reported that 1981 prices at commerical landfills ranged from $55 to $240 per t depending on the type of waste and whether it was in drums or

Table 14. Cost comparisons among hazardous waste treatment and disposal technologies.[a]

Technology	Economic Life (yr)	Life Cycle Average Cost (US$/m³) at L/s				
		63	126	189	252	316
Precipitation/Floculation/ Sedimentation	10	0.45	0.37	0.33	0.32	0.31
Filtration	10	0.61	0.52	0.46	0.43	0.41
Evaporation	5	2.24	2.04	1.98	1.95	1.93
Flotation	10	0.33	0.27	0.24	0.22	0.21
Oil/Water Separation	10	0.13	0.08	0.07	0.07	0.08
Chemical Oxidation/Reduction	5	1.15	0.99	0.98	1.13	1.35
Carbon Adsorption	7	5.35	3.21	2.48	2.14	1.93
Activated Sludge	10	0.81	0.60	0.53	0.68	0.82
Evaporation Pond	20	1.06	0.98	0.95	0.94	0.94
		Life Cycle Average Cost (US$/t) at kg/h				
		454	907	1361	1814	2268
Incineration	5	565.70	544.44	538.77	535.55	536.15
Land Disposal	20	340.26	201.19	150.73	125.35	110.25
Chemical Fixation with Solids	NA	198.41	198.41	198.41	198.41	198.41
Chemical Fixation without Solids	NA	52.91	52.91	52.91	52.91	52.91
Encapsulation	7	102.78	94.51			

[a] Source: Hansen and Rishel 1980

Table 15. Treatment and disposal fees at European facilities.[a]

Facility	Fees (Deutsche Mark/t)[b]		
	Physical Chemical Treatment	Incineration	Landfill
GSB (March/81) Ebenhausen	70 to 435	105 to 325	60 to 105
ZVSMM (September/81) Schwabach	65 to 270	125 to 210	45
HIM Biehesheim/Frankfurt (September/82)	385	170	100

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[a] Source: site visits

[b] 2.0 DM = 1.0 Can $ at time of site visits

Table 16. Treatment and disposal fees at North American facilities.[a]

Facility	Fees (US$/t)	
	Incineration	Landfill
Casmalia Resources Casmalia, California	-	13 to 120 300 (PCB)
BKK West Covina, California	-	25 to 200
MSD of Greater Cincinnati Cincinnati, Ohio	57 to 158	-
Tricil Corunna, Ontario	27 to 62[b] (approx.)	30 to 40[b] (approx.)

[a] Source: site visits

[b] Prices in Can $

Table 17. Annual revenue per unit required to offset incremental costs due to RCRA part 264 regulations: landfill by unit size.[a,b]

Size t/a	Single Synthetic Liner		Double Liner (synthetic/clay)		Double Synthetic Liner	
	Per Year (US$000)	Per t US$	Per Year (US$000)	Per t US$	Per Year (US$000)	Per t US$
500	31	62	52	104	43	86
2 000	49	25	94	47	82	41
5 000	79	16	164	33	145	29
7 000	98	14	207	30	184	26
15 000	149	10	323	22	290	19
35 000	277	8	622	18	561	16
60 000	379	6	862	14	779	13
123 000	566	5	1306	11	1180	10

[a] Source: U.S. EPA 1982

[b] Costs shown are those estimated for onsite landfills in these size categories. They are slightly different from costs estimated for offsite landfills. If costs were based on offsite landfills, double liner (synthetic/clay) costs would be lower.

bulk. These costs did not include transportation which averaged about $0.09 per t-km.

Table 18 estimates the cost (US$) for implementation of the regulations to land treatment operations for various size operations. EPA reported that prices for commerical land treatment in 1981 ranged for $5 to $24 per t.

Table 18. Annual revenue per unit required to offset incremental costs due to RCRA part 264 regulations: land treatment by unit size.[a]

Size (hectare)	Basic cost (no corrective action)	
	per year (US$000)	per t[b] US$
0.7	17	48
2.6	19	14
50	45	11
30	122	8
100	361	7

[a] Source: U.S.EPA 1982

[b] Based on a waste application rate of 510 t/ha-a. In practice the amount of waste processed per hectare is highly variable.

8. CONCLUSIONS

8.1 CRITERIA FOR RESIDUE MANAGEMENT

An overview of all the information gathered throughout the duration of this study leads to several conclusions regarding hazardous waste residue management for Alberta. These will be listed in the order which they arise in this report.

1. Comparison of hazardous waste inventory projections for Alberta with similar but independent projections for Ontario and experience in California shows a remarkable similarity in the distribution of waste quantities. While this does not verify the quantities projected for Alberta, it offers some hope that the projected distribution of waste types may be realistic.

2. Comparison of literature information on hazardous waste treatment and disposal technology with current practice in Europe and North America shows some significant differences. While the literature lists dozens of possibilities, the technologies observed at actual operating facilities could be grouped into only 12 major categories. Given that the projected waste inventory for Alberta does not exhibit any significantly unique or difficult challenges it would be prudent to implement proven technologies rather than attempting to pioneer new technology.

3. Comparison of European and North American facilities demonstrated some significant differences. Primarily, many European commercial service facilities were centralized integrated plants with several technologies involved. North American facilities on the other hand were more specialized with treatment facilities specifically tailored to a local market.

4. The general level of site maintenance and cleanup at European treatment facilities appeared better than at North American facilities but, with the exception of incineration, the technology was not noticeably more sophisticated. The best European facilities for overall appearance were government subsidized, usually by assistance with capital acquisition. No equivalent models of government subsidization could be found in North America.

5. Comparison between Europe and North America of the proportion of wastes handled which are ultimately disposed to landfill (or equivalent) showed about 50% for European facilities and 68% for North American facilities. These figures must be viewed as biased by the choice of facilities surveyed. Consequently, they are not representative of the total waste inventory for the jurisdictions in either case. However, the high proportion of landfilled residues for the European plants, which were biased to those with incineration and other treatment technology, demonstrates the importance of the landfill even for high technology plants.

6. A rough calculation of the scale of landfill required for hazardous waste residues in Alberta based upon approximately 70% of the total waste inventory requiring land disposal indicates that a relatively small land area would be required (about the equivalent of 10 single family residential lots required per year.)

7. Review of the literature and site visit information regarding residue generation potential for various treatment technologies indicated that generation rates were variable and dependent upon waste make-up. Generation factors ranged from: .003 to 0.5 t residue/t of waste processed for physical chemical treatment (typical values ≈ 0.1 t/t); 0.001 to 0.008 t residue/t of waste processed for biological treatment; and 0.03 to 0.20 t bottom ash residue/t of waste incinerated for rotary kiln incinerators (typical values < 0.20 t/t).

8. With the exception of biological sludges, whose properties are well documented elsewhere, and oily sludges, the other residues were found to be primarily inorganic in nature. Since the oily sludges are generally incinerable, the major noxious consituents of treatment residues appear to be inorganic. Specifically, toxic metals formed relatively high fractions of some residue materials.

9. Stabilization processes appear feasible for handling the types of residues likely to be encountered. In general, their advantages outweigh their disadvantages provided landfill capacity is not severely limiting. However, the security of trace organic

compounds in stabilized wastes is largely undocumented, although the decreased permeability of properly stabilized residues should reduce leaching potential.

10. A policy banning disposal of liquids to the residue landfill is justified given the realities of landfill containment.

11. Information on leachate from hazardous waste landfills associated with high technology plants is limited. However, in the case of two German plants which were not practicing residue stabilization, leachate was found to be highly polluted including a high organic content. In one case, this may reflect the influence of an adjacent sanitary landfill. Based on this limited data and knowledge of the metals content of many residues, it would be wise to employ the best current technology to prevent leachate formation, to provide for collection of leachate which might still form, and to contain any leachate which cannot be collected.

12. The relatively small physical size of the landfill likely to be required should provide ample scope for implementation of the foregoing technological measures while reserving the attenuation capacity of the soil as the ultimate safety factor at the site. Estimates provided by the U.S. EPA project a 1981 cost of US $14 per t for a double liner at a 60 000 t/a landfill.

13. Land treatment is an emerging technology which may offer some promise for the Alberta facility provided climatic factors can be overcome. However, this option should be approached cautiously and should be based upon pilot scale experimentation before being committed to full scale operation.

14. Deep well disposal at the centralized hazardous waste treatment facility is unlikely to be a major factor unless a commercial demand arises for direct injection of untreated wastes. Although deep well disposal now widely exists in Alberta industry, a clearer policy for deep well disposal should be developed to be consistent with practices intended for the centralized facility. A logical policy could be based upon the probable consequences of disposal well failure, independent of how unlikely such failure may be. Such a policy would eliminate the disposal of wastes capable of

contaminating aquifers and posing a health risk to groundwater consumers without providing any sensory (taste or odour) warning of the contamination. This policy would allow (but not necessarily encourage) the continued deep well disposal of most petroleum related wastes which do not pose a significant incremental risk relative to the thousands of oil and gas wells already existing in the province.

8.2 RESEARCH NEEDS

The extensive experience gained from site visits together with the literature review has highlighted several areas where research is needed to improve current practices in hazardous waste treatment and disposal. Recommendations are listed without order of priority.

1. Current knowledge on the interactions between different wastes and between wastes and liner systems is weak. Research should be conducted at the operating facility to attempt to characterize any possible interactions between the major residue categories and the landfill liner.
2. Current monitoring techniques for characterizing wastes prior to incineration do not consistently provide significant knowledge concerning effects upon refractory brick life or related factors which have a large bearing on incineration cost. Research should be initiated to consider such factors with the aim of developing rapid test procedures which would allow waste charges to be adjusted for problem wastes.
3. The effectiveness of common stabilization technologies in retaining organic constituents is not well documented at present. In general, most stablization technologies would be expected to be ineffective at retaining high concentrations of organic solutes. However, ongoing research should be conducted at the operating facility to evaluate the

success of stabilization technology options at fixing unavoidable trace organic constituents.

4. Land treatment may offer a suitable alternative to incineration for destruction of unconcentrated organic wastes but site specific research and pilot scale studies will be required to demonstrate this technology in Alberta's climate.
5. The operating costs of incineration may be uneconomic depending upon the costs for the addition of supplemental fuel to low thermal value wastes. Economic and technological research should be conducted on the feasibility of using waste materials such as oil sands coke as a lower cost supplemental fuel.

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10. APPENDICES

10.1 NORTH AMERICAN AND EUROPEAN SITE VISIT INFORMATION AND CONTACTS

Table 19. North American and European site visit information and contacts.

Company	Facility Contact Facility Locations	Processes	
		Treatment	Disposal
ABCO Industries Thermal Oxidation Division P.O. Box 3335 Roebuck, SC, USA, 29376	Mr. C. Milford (803) 576-6821 Roebuck	incineration	landfill (offsite)
American Recovery Co. Inc. 1901 Birch St. Baltimore, MD, USA, 21226	Mr. Norm Cohen (301) 355-0623 Baltimore	Fuels recovery neutralization complexation	landfill (offsite)
Applied Environmental Services 1 Shore Road P.O. Box 329 Glenwood Landing, NY, USA 11547	Mr. George Lawrence (516) 759-2273 Glenwood Landing	fuels recovery	landfill (offsite)
Browning-Ferris Industries Inc. 7890 Solley Road Glen Burne, MD, USA, 21061	Mr. Norman J. Coutant Operations Manager (301) 437-4720 Glen Burne		landfill (onsite)

continued ...

Table 19. Continued.

Company	Facility Contact Facility Locations	Processes	
		Treatment	Disposal
Browning-Ferris Industries, Inc. P.O. Box 5416 Lake Charles, LA, USA 79696	Mr. Austin R. Arabie Tech. Manager Calcasieu Facility (318) 527-6857 Calcasieu		landfill (onsite) deep well injection (onsite)
Browning-Ferris Industries, Inc. P.O. Box 669 Livingston, LA, USA 70754	Mr. Chuck Sacher Manager Livingston Facility (504) 686-7252 Livingston		landfill (onsite)
BKK Corporation 255-237th Street P.O. Box 3038 Torrance, CA, USA, 90510	Mr. Tom Nuckols (213) 539-7150 West Covina		landfill (onsite)
Casmalia Resources P.O. Box 5275 Santa Barbara, CA, USA, 93108	Mr. Jim McBride (805) 937-8449 Casmalia	oil separation neutralization	landfill (onsite) land treatment (onsite)

continued ...

Table 19. Continued.

Company	Facility Contact	Processes	
	Facility Locations	Treatment	Disposal
Cecos International, Inc. P.O. Box 619 Niagara Falls, NY, USA 14302	Mr. E.R. Gedeon (719) 731-3281 Niagara Falls	neutralization precipitation oxidation reduction adsorption biological	landfill (onsite)
Cecos/CER Co. 4879 Spring Grove Ave. Cincinnati, OH, USA, 45323	Mr. Timothy J. Henry Customer Service Manager (513) 681-5731 Cincinnati, Williamsburg	filtration adsorption	landfill (onsite)
Chemical Processors, Inc. 5501 Airport Way S. Seattle, WA, USA, 98108	Mr. Mike Keller (206) 767-0350 Seattle, Tacoma	solvent recovery oil separation neutralization oxidation reduction	landfill (offsite)
Chem-Security Systems, Inc. Star Route Arlington, OR, USA, 97812	Mr. Frank G. Dement Arlington Site (503) 454-2777 Arlington	oxidation	landfill (onsite) land treatment (onsite)

continued ...

Table 19. Continued.

Company	Facility Contact Facility Locations	Processes Treatment	 Disposal
Chemical Waste Management Inc. P.O. Box 471 Kettleman City, CA, USA, 93239	Mr. Craig McKenzie (209) 386-9711 Kettleman City		landfill (onsite) land treatment (onsite)
Chemical Waste Management Inc. P.O. Box 1296 138th & Calumet Expressway Calumet City, IL, USA, 60408	Mr. Tom N. Tomaszewski General Manager (312) 891-1500 Calumet City	neutralization filtration	landfill (onsite)
Chemical Waste Management Inc. P.O. Box 55 Emelle, AL, USA, 35459	Dr. Roger D. Henson Asst. General Manager (205) 652-9531 Emelle	incineration	landfill (onsite)
Chemical Waste Management Inc. P.O. Box 471 Kettleman City, CA, USA, 93239	Mr. Craig McKenzie (209) 386-9711 Round Mountain, Kern Country		landfill (onsite) land treatment (onsite)

continued ...

Table 19. Continued.

Company	Facility Contact	Processes	
	Facility Locations	Treatment	Disposal
Chemical Waste Management Inc. Lake Charles Facility Route 2, Box 1955 Sulphur, LA, USA 70663	Mr. Norb Bolda (318) 583-2144 Sulphur		landfill (onsite)
Chemical Waste Management Inc. P.O. Box 2563 Port Arthur, TX, USA, 77640	Mr. Norb Bolda (713) 736-2821 Port Arthur		landfill (onsite) deep well injection
Cincinnati, M.S.D. of Greater 1600 Gest Street Cincinnati, OH, USA, 45204	Mr. John H. Trapp Industrial Wastes Chemical Engineer (513) 352-4828 Cincinnati	incineration	landfill (offsite)
Energy Systems Co. (ENSCO) P.O. Box 1975 El Dorado, AR, USA, 71730	Mr. Arch P. Pettit General Manager (501) 863-7173 El Dorado	incineration	landfill (offsite)

continued ...

Table 19. Continued.

Company	Facility Contact	Processes	
	Facility Locations	Treatment	Disposal
IT Corporation 4575 Pacheco Blvd. Martinez, CA, USA, 17404	Mr. Paul T. Kaufmann Senior Vice President (415) 228-5100 Martinez, Benecia	neutralization oxidation solvent recovery incineration	landfill (onsite) land treatment (onsite)
Liqwacon/Envirite 1600 Pennsylvania Avenue York, PA, USA, 17404	Mr. Curvin Snyder III Manager, York Operations (717) 846-1900 York	neutralization oxidation reduction filtration	landfill (offsite)
Rollins Environ. Service (LA) P.O. Box 73877 13351 Scenic Highway Baton Rouge, LA, USA, 70807	Mr. Arthur E. Rubenstein (504) 778-1234 Baton Rouge Plaquemine	incineration neutralization precipitation oil separation biological	landfill (onsite) deep well injection (offsite)
Rollins Environ. Services (NJ) P.O. Box 221 Bridgeport, NJ, USA, 08014	Mr. R.C. Gregory (302) 429-2768 Bridgeport	incineration neutralization precipitation	landfill (offsite)

continued ...

Table 19. Continued.

Company	Facility Contact Facility Locations	Processes Treatment	 Disposal
Rollins Environ. Services (Tx) P.O. Box 609 2027 Battleground Road Deer Park, TX, USA, 77536	Mr. W. Doug Cooper (713) 479-6001 Deer Park	incineration neutralization precipitation biological	landfill (onsite)
SCA Chemical Services Inc. 11700 South Stony Island Ave. Chicago, IL, USA, 60617	Mr. Clark J. Rose Vice President/ General Manager (312) 646-5700 Chicago	incineration	landfill (offsite)
SCA Chemical Services Box 200, 1550 Balmer Road Model City, NY, USA, 14107	Mr. G. Spiria (716) 754-8231 Model City	oxidation reduction neutralization precipitation filtration adsorption biological	landfill (onsite)

continued ...

Table 19. Continued.

Company	Facility Contact	Processes	
	Facility Locations	Treatment	Disposal
SCA Chemical Services Inc. 1280 Wall Street, West P.O. Box 808 Lyndhurst, NJ, USA, 07081	Dr. Richard B. Moon Director of Technical Development (201) 935-7850 Newark	oxidation reduction neutralization filtration oil separation fuels recovery	landfill (offsite)
SCA Chemical Services Inc. Box 255, Route I Pinewood, SC, USA, 29125	Mr. Larry G. Johnson Manager Environmental Affairs (803) 452-5003 Pinewood		landfill (onsite)
Southeastern Waste Treatment P.O. Box 1697 1015 New South Harris Street Dalton, GA, USA, 30720	Mr. Roy Baggett Vice-President (404) 278-0091 Dalton	incineration precipitation	landfill (offsite)
Systech Corporation 1640 Antioch Pike Antioch, TN, USA, 37013	Mr. Doug Ezell (615) 833-2059 Antioch	neutralization precipitatioin oxidation reduction oil separation filtration	landfill (offsite)

continued ...

Table 19. Continued.

Company	Facility Contact	Processes	
	Facility Locations	Treatment	Disposal
Tricil (Sarnia) Ltd. P. O. Box 786 Corunna, Ont. CANADA NON 1G0	Mr. Eric Hunter Branch Manager (519) 864-1021 Corunna	incineration	landfill (onsite)
	U.S. Industrial Onsite Facilities		
Eastman Kodak Co. B-23 Kodak Park ETS Division Rochester NY, USA, 14650	Mr. David S. Austin (716) 722-2363 Rochester	incineration	
E.I. DuPont de Nemours & Co. Chambers Works Deepwater, NJ, USA, 08023	Mr. Ted E. Lewis General Supt. Environmental Dept. (609) 299-5000 Deepwater	biological treatment (PACT)	landfill (offsite)

continued ...

Table 19. Continued.

Company	Facility Contact	Processes	
	Facility Locations	Treatment	Disposal
3M Co. Box 33331 St. Paul, MN, USA, 55133	Dr. Russell H. Susag Director Environmental Operations (612) 778-4468 St. Paul	incineration	landfill (offsite)

continued ...

Table 19 Continued

Company	Facility Contact Facility Locations	Processes	
		Treatment	Disposal
	European Facilities		
AVR[a] Prof. Gerbrandyweg 10 3197 kk. Rotterdam-Botlek Postbus 1120 3180 AC Rozenburg The Netherlands	Mr. D. denOuden (1) 01819-1411 Rotterdam	incineration	landfill (offsite)
Gerep Z.I. de MITRY COMPANS Rue Jacquard 77290 Mitry Mory France	Mr. G. Millot President Directeur General (6) 427 16 97 Mitry Mory	incineration neutralization soldification	landfill (offsite)
GSB 8076 Ebenhausen-werk Fed. Rep. Germany	Dr. J.D. Herbell (84) 53-626 Ebenhausen, Gallenbach	incineration neutralization oxidation reduction oil separation precipitation filtration	landfill (Gallenbach)

continued ...

Table 19.Continued.

Company	Facility Contact Facility Locations	Processes	
		Treatment	Disposal
HIM Kranzplatz II 6200 Weisbaden Fed. Rep. Germany	Dr. P. Schoner Tech. Leiter (6121) 373074-78 Biebesheim, Frankfurt, Kassel, Mainflingen	incineration neutralization oxidation reduction oil separation precipitation filtration	landfill (Mainflingen)
Kali und Salz AG[a] Friedrich Eberstrasse 160 P.O. Box 102029 D3500 Kassel Fed. Rep. Germany	Dr. G. Johnsson (0561) 301395 Herfa-Neurode		Deep mine storage
Kommunekemi A/S Lindholmvej 3 DK-5800 Nyborg Denmark	Mr. J. Toffner-Clausen Technical Director (9) 311244 Nyborg, Klintholm	incineration neutralization oxidation reduction oil separation precipitation filtration	landfill (Klintholm)

continued ...

Table 19. Continued.

Company	Facility Contact	Processes	
	Facility Locations	Treatment	Disposal
KVR Ruttenscheider Str. 66 4300 Essen 1 Fed. Rep. Germany	Hr. G. Rimmasch (201) 72260 Herten, Duisberg, Gelsenkirchen	incineration neutralization oxidation reduction oil separation precipitation filtration	landfill (Gelsenkirchen)
Plafora[a] Zone Industriel de la Plane de l'Ain St. Valbas 01150 Laquieu France	M.C. Peker (074) 61 03 55 St. Valbas	incineration reduction precipitation filtration oil separation	landfill (offsite)
Re-Chem International Ltd.[a] 80 Shirley Road Southampton, England SOI 3EY	Mr. L. Baker (0703) 29255 Fawley	incineration neutralization oxidation reduction precipitation filtration oil separation	landfill (offsite)

continued ...

Table 19. Continued.

Company	Facility Contact	Processes	
	Facility Locations	Treatment	Disposal
SARP Industries[a] 18 Rue des Tournelles 75004 Paris France	M. J.L. Biros 2669150 Limay	incineration neutralization reduction precipitation filtration oil separation	landfill (offsite)
ZVSMM 56 Rotherstrasse Fed. Rep. Germany	Hr. Hartinger (9122) 85-058 Schwabach	incineration neutralization oxidation reduction oil separation precipitation filtration	landfill (onsite)

[a] Plants surveyed from site visit reports (Rivoche 1980; Proctor & Redfern 1982b) but not visited in person.

continued ...

Table 19. Concluded.

Company	Facility Contact	Processes	
	Facility Locations	Treatment	Disposal
European Industrial Onsite Facilities			
BASF AG 6700 Ludwigshafen Fed. Rep. Germany	Dr. R. Pirzer (0621) 6055043 Ludwigshafen, Flotzgrun)	incinceration biological	landfill (Flotzgrun) deep mine (Herfa Neurode)
BAYER AG 5090 Leverkusen, Bayerwerk Fed. Rep. Germany	Dr. H. Fuhr (0214) 30 5079 Leverkusen	incineration biological	landfill (Leverkusen) deep mine (Herfa, Neurode)
HOECHST AG 6230 Frankfurt 80	Dr. H. Schaum (0611) 305 6118 Frankfurt, Asslar	incineration biological	landfill (Asslar) deep mine (Herfa, Neurode)

10.2 UNIVERSITY OF CALIFORNIA AT DAVIS (UCD) WASTE CLASSIFICATION SYSTEM

Table 20. University of California at Davis (UCD) Waste Classification System.

UCD WASTE CATEGORY	DESCRIPTION
INORGANICS	
(11) ACIDIC SOLUTION	Typically hydrochloric acid (HCl), sulphuric acid (H_2SO_4), or nitric acid (HNO_3)
(111) Acidic solutions with heavy metals	Including antimony, arsenic, barium, beryllium, boron, cadmium, chromium, copper, idium, lead, manganese, mercury, molybdenum, nickel, selenium, silver, tin, vanadium, and/or zinc
(112) Acidic solutions with other metals and non metals	Typically contain an alkali metal, i.e., sodium (Na), potassium (K)
(113) Other acidic solutions	Acidic solutions not containing metals or non-metals
(12) AKALINE SOLUTIONS	Usually contain sodium hydroxide (NaOH), potassium hydroxide (KOH), or ammonium hydroxide (NH_4OH)
(121) Alkaline solutions with heavy metals	See (111) above
(122) Alkaline solutions with other metals and non-metals	See (112) above
(123) Other alkaline solutions	Alkaline solutions not containing metals or non-metals

continued ...

Table 20. Continued.

UCD WASTE CATEGORY	DESCRIPTION
(13) METAL-FINISHING SOLUTIONS	From process identification on manifest, i.e., "metal plating", "pickling bath", etc.
(131) Metal-finishing solutions-acidic	Typically containing copper, tin, lead, or cadmium
(132) Metal-finishing solutions-alkaline	See (131) above
(133) Spent pickle liquor	Acids typically containing iron, fluoride, hydrochloric acid, sulphuric acid, nitric acid
(14) OTHER AQUEOUS (SALT) SOLUTIONS	Acidic or basic solutions which are neutralized by generator, yielding a salt solution
(141) Other aqueous (salt) solutions with heavy metals	See (112) above
(143) Solution containing other reactive anions	See (113) above
[a] (144) Other aqueous solutions	Aqueous solutions (14) other than (141), (142), (143), (145), (146), or (147)
(145) Brine	
(146) Solution containing cyanide	
(147) Solution containing sulfide	
(15) INORGANIC SOLIDS	
(151) Inorganic solids	Activated carbon, cement, etc.
(152) Inorganic chemicals	Miscellaneous salts, etc.

continued ...

Table 20. Continued.

UCD WASTE CATEGORY	DESCRIPTION
(16) OTHER INORGANIC WASTES	
[a] (161) Asbestos-containing wastes	
[a] (162) Aluminum or tin wastes	
(165) Spent catalyst	Typicallly silica-alumina or zeolilte, containing trace metals and carbonaceous deposits
(167) Unidentified inorganic wastes	
ORGANICS	
(21) SPENT SOLVENTS	
Halogenated Solvents	Contain chlorine (e.g., trichloroethylene), bromine, or fluorine
(211) Spent solvents with heavy metals	See (111) above
(212) Spent solvents with other metals	See (112) above
(213) Other halogenated solvents, including mixed	Trichloroethylene, chloroform, carbon tetrachloride, etc.
Non-halogenated Solvents	Typically include oxygenates, e.g., acetone, methylethylketone, etc.
(214) Spent solvents with heavy metals	See (111) above
(215) Spent solvents with other metals or non-metals	See (112) above

continued ...

Table 20. Continued.

UCD WASTE CATEGORY	DESCRIPTION
(216) Other non-halogenated solvents, including mixed	Solvents identified, and containing no metals
(217) Unspecified solvents	Alcohols and mixtures of solvents
(22) OTHER ORGANIC LIQUIDS	
(221) Other organic liquids with halogens and metals	See (112) above
(222) Other organic liquids with halogens	Chlorine, bromine, fluorine only
(223) Other organic liquids with heavy metal only	See (111) above
(224) Other organic liquids	Not classified as (221), (222), or (223)
(22) ORGANIC RESIDUES	Frequently include such contaminants as chloroform, acetone, trichloroethylene, etc. These solutions commonly result from cleaning and degreasing operations
(225) Aqueous solution with non-halogenated organic residues < 10%	
(226) Aqueous solution with halogenated organic residues < 10%	
(227) Aqueous solution with non-halogenated organic residues > 10%	
(228) Aqueous solution with halogenated organic residues > 10%	

continued ...

Table 20. Continued.

	UCD WASTE CATEGORY	DESCRIPTION
	(23) ORGANIC SOLIDS	
a	(231) Organic solids with halogens	Polyvinyl
a	(232) Organic solids without halogens	Polyethylene
	(24) OTHER ORGANIC WASTES	
	(241) Pesticides and wastes	Pesticide production, waste and rinse water containing pesticides, and pesticide containers not clearly specified as empty
	(242) Polychlorinated biphyenyls (PCBs) and material containing PCBs	Transformer fluids, contaminated materials including transformer carcasses and soil
	(243) Pharmaceuticals and wastes	
	(244) Photochemicals and wastes	Virtually all from photoprocessing laboratories
	(245) Off-specification or aged organics	Miscellaneous
	(247) Halogenated still bottoms	
	(248) Still bottoms (distillation residues) without halogens	
	(251) Liquid tannery wastes	Many components, including aqueous chromate solutions, and organic materials such as fat and hide
	(252) Solid or sludge tannery wastes	
a	(253) Detergent and soap	Liquid, aqueous waste solutions, and organic solids from production or cleaning operations

continued ...

Table 20. Continued.

	UCD WASTE CATEGORY	DESCRIPTION
	(254) Adhesives or glue	Organics not listed in above categories
a	(255) Unspecified organic wastes	
	(257) Phenolic Wastes	
	(258) Waste tars and residues	
	(26) POLYMERIC MATERIAL AND WASTES	
	(261) Polymeric resin	Phenolic, epoxy, polyester, urethane, etc., per component data
	(262) Latex and wastes	Paint, latex and acrylic resins
	(263) Other polymeric wastes, theorm-plastic, or not stated	Off-specification materials, crushed cases, discarded material from polymer reactors
	(264) Other polymeric wastes, thermoset	
	(27) BIOLOGICAL WASTES	
a	(271) Sewage sludge	
a	(272) Other biological wastes	Including animal fat, molasses wastes, and dough
	(28) OILY WASTES	
	(281) Waste oil and mixed oil	May contain solvents or metals
	(282) Oily tank bottoms	Sludge
	(283) Oily mud or sediment and water	

continued....

Table 20. Continued.

UCD WASTE CATEGORY	DESCRIPTION
(284) Oily acidic solids	
(285) Oily alkaline solids	
(286) Oil/water separator sludge	
(288) Oily wastes with heavy metal contaminants	
(289) Oily wastes with water	See (111) above.
OTHER SLUDGES	
(41) RELATIVELY INERT SLUDGES	
* (412) Filter cake	Contaminated filter material, e.g., diatomaceous earth
* (413) Gas scrubber sludge	From gas cleaning operations
(416) Ink sludge	May contain solvents, lead, or chromium
(417) Alum and gypsum (mineral) sludges	
(43) METAL SLUDGE	
(431) Heavy-metal sludge	See (111) above
(433) Other metal sludges	Typically contain salts of iron, aluminum and/or alkali metals

continued ...

Table 20. Continued.

	UCD WASTE CATEGORY	DESCRIPTION
	(44) OTHER SLUDGES	
	(441) Lime sludge	From neutralization processes; may contain heavy metals
a	(442) Phosphate sludge	
	(443) Sulphur sludge	Includes sludge with high content of non-heavy metal sulfides
	(444) Cyanide bearing sludge	
	(445) Plating or metal finishing sludge	See (131), (132), and (133)
	(446) Degreasing sludge	From cleaning of metal parts; contains solvents
	(447) Tetraethyl lead sludge	
a	(453) Paper sludge/pulp	Paper and cardboard manufacture source
	(454) Paint sludge	Many possible components, including heavy metal (chromium) and organic solvents or components not stated
	(455) Paint sludge without heavy metals	
a	(456) Other waste treatment sludge	Sludges not otherwise identified due to lack of composition data
a	(457) Sludges with organic residues	Includes some halogenated components

continued ...

Table 20. Continued.

	UCD WASTE CATEGORY	DESCRIPTION
	(50-53) MISCELLANEOUS	
	(509) Gas cylinders or containers	
a	(510) Flue-gas scrubber liquid	
a	(511) Rinse water and wastewater	Contains small units of oil, solvent, metals, and/or mud; also bilge water
	(21) Spill clean-up	Includes miscellaneous organics, liquid fuels
	(513) Laboratory waste chemicals	
a	(514) Contaminated soil and sand	
a	(515) Drilling mud	
	(518) Dust-collector wastes	Typically dry lime
a	(519) Fly ash and retort ash	Combustion-generated particulates: mineral matter plus some carbon
	(521) Spent cartridge filters	Gas/liquid cleaning
	(523) Tank bottom sediments	
a	(524) Chemical toilet wastes	
a	(525) Metal dust and machining wastes	Primarily ferrous and aluminum based alloys
a	(526) Cannery wastes	
a	(527) Mud/sediment and water	

continued ...

Table 20. Concluded.

	UCD WASTE CATEGORY	DESCRIPTION
	(528) Pathological wastes	
	(529) Explosive wastes	
[a]	(530) Contaminated pallets	
	(531) Contaminated rags	
	(532) Equipment and/or containers contaminated with pesticide	
[a]	(533) Contaminated equipment and containers	Contaminants not stated
[a]	(535) Totally unspecified wastes	Used only from California manifest purposes

[a] indicates waste category not included in Ontario survey (Proctor & Redfern 1982a).

10.3 AGGREGATION OF ALBERTA WASTE CATEGORIES ACCORDING TO MODIFIED ONTARIO CATEGORIES BASED ON UCD CODE SYSTEM

Table 21. Aggregation of Alberta waste categories according to modified Ontario categories.

ONTARIO WASTE CATEGORIES	UCD CODES	ALBERTA WASTE ESTIMATES DESCRIPTION		QUANTITY t/a
A. ORGANIC SLUDGES AND STILL BOTTOMS (NO OIL)				
Organic sludges containing metals Halogenated still bottoms Non-halogenated still bottoms	247, 248, 252, 257, 261, 263, 446, 523, 529	15. Organic tannery waste		2100
		23. Plastic, resins, latex		460
		24. Phenols		60
		35. Tank bottoms		1300
			Subtotal	3920
B. SOLVENTS & ORGANIC SOLUTIONS				
Halogenated Non-halogenated Mixed	211, 212, 213, 214, 215, 216, 217, 221, 222, 223, 224	3. Solvents (halogenated)		900
		4. Solvents (non-halogenated)		5600
			Subtotal	6500
C. OILS & GREASES				
Waste lube oil Other oils and grease	264, 281, 282, 283, 284, 285, 286, 288, 289, 447	2. Oils		20000
			Subtotal	20000
OIL/WATER MIXTURES				
Emulsified and free oil/water mixtures				
ORGANIC AND OIL RESIDUALS				
Leaded gasoline Unleaded gasoline and organics food waste oil				

continued ...

Table 21. Continued.

ONTARIO WASTE CATEGORIES	UCD CODES	ALBERTA WASTE ESTIMATES DESCRIPTION	QUANTITY t/a
D. **HEAVY METAL SOLUTIONS AND RESIDUALS**			
Spent plating or etching Rinse and less concentrated aqueous solutions Sludges from plating and etching lines Sludges from treatment of solutions containing metals	111, 112, 113, 121, 122, 123, 131, 132, 133, 141, 142, 143, 244, 251, 431, 433, 445, 523	6. General mixed metal bearing sludge	5000
		8. Chromium	100
		18. General mixed aqueous (water) metal bearing sludge	50
		19. Acids with heavy metals	500
		20. Acids	23700
		21. Alkalis with heavy metals	70
		22. Alkalis	5500
		32. Scrap batteries	10
		39. Photochemicals	1100
		Subtotal	36030
E. **MISCELLANEOUS CHEMICALS AND PRODUCTS**			
Organic chemicals Inorganic chemicals Salts	145, 152, 243, 245, 416, 513	14. Ink	10
		31. Ammonia	10
		36. Chemicals	12200
		Subtotal	12220

continued ...

Table 21. Continued.

ONTARIO WASTE CATEGORIES	UCD CODES	ALBERTA WASTE ESTIMATES DESCRIPTION	QUANTITY t/a
F. PAINT AND ORGANIC RESIDUALS			
Latex paint and sludge Solvent based paint and sludge Wash and rinse waters	254, 258, 262, 454, 455	13. Textile waste	10
		17. Paint	300
		Subtotal	310
G. AQUEOUS SOLUTIONS WITH ORGANICS (90% H_2O)			
Alcohols and organic acids Halogenated solvents Non-halogenated solvents	225, 226, 227, 228	None inventoried	
		Subtotal	0
H. ANION COMPLEXES			
Cyanide Sulphide Other Complexes	146, 147, 444	25. Cyanides	1200
		Subtotal	1200
I. SLUDGES AND INORGANIC RESIDUALS			
Ash Spent catalyst	151, 165, 167, 417, 441, 443, 504, 518	16. Dust and scrubber sludge	90
		33. Waste activated carbon	40
		37. Sulphur	200
		Subtotal	330

continued ...

Table 21. Continued.

ONTARIO WASTE CATEGORIES	UCD CODES	ALBERTA WASTE ESTIMATES DESCRIPTION		QUANTITY t/a
J. PESTICIDE AND HERBICIDE WASTES				
High concentration organics High concentration with metals Cleanup water and dilute solutions	241, 532	12. Pesticides		180
			Subtotal	180
K. PCB WASTES				
High concentration liquids (>500 ppm) Medium concentration liquids (<500 ppm) Contaminated soil (<50 ppm)	242	1. PCB		10
			Subtotal	10
L. CLEAN-UP RESIDUALS				
Solvent and organic waste Inorganic and metals Pesticides and herbicides	512, 521, 528, 531	None inventoried		0
			Subtotal	0
			TOTAL	80700

continued ...

Table 21. Concluded.

ONTARIO WASTE CATEGORIES	UCD CODES	ALBERTA WASTE ESTIMATES DESCRIPTION		QUANTITY t/a
N. NOT INCLUDED IN SCOPE OF ONTARIO SURVEY		10. Aluminum		70
		26. Phosphate sludge		
		28. Contaminated containers & equipment		10
		29. Contaminated soil and sand		460 2500
		30. Asbestos		3700
		34. Infectious wastes		1200
		38. Flyash	TOTAL NOT INCLUDED	8090

10.4 RCRA PART 264 HAZARDOUS WASTE LANDFILL REGULATIONS (EXCERPT)

Subpart N—Landfills

264.300 Applicability.
264.301 Design and operating requirements.
264.302 Double-lined landfills: Exemption from Subpart F ground-water protection requirements.
264.303 Monitoring and inspection.
264.304–264.308 [Reserved]
264.309 Surveying and recordkeeping.
264.310 Closure and post-closure care.
264.311 [Reserved]
264.312 Special requirements for ignitable or reactive waste.
264.313 Special requirements for incompatible wastes.
264.314 Special requirements for liquid waste.
264.315 Special requirements for containers.
264.316 Disposal of small containers of hazardous waste in overpacked drums (lab packs).
264.317–264.339 [Reserved]

* * * * *

I. Landfills (Part 264, Subpart N)

Subpart N contains the design and operating standards for landfills used to dispose of hazardous wastes. The basic requirements are: (1) A liner to prevent migration of wastes out of the landfill and into the subsurface soil or ground water or surface water during the landfill's active life (with an exemption for existing portions, such as cells or trenches that already contain wastes); (2) a leachate collection and removal system; (3) control of run-on and run-off; and (4) capping the wastes at closure and conducting post-closure care. An exemption from the ground-water protection requirements of Subpart F is provided for landfills that have double liners and leak detection systems. A waiver of the liner and leachate collection and removal requirements is provided if the owner or operator demonstrates to the Regional Administrator that hazardous constituents will never migrate from the landfill into ground or surface water.

Many of the features of the Subpart N regulations (liners; leachate collection and removal systems; and double liners and leak detection systems installed to qualify for exemptions from Subpart F) are explained in the general discussion of design and operating standards (see Section VII.E. of this preamble) or in the discussion of analogous provisions in Subparts K and L for surface impoundments and piles (see Section VII.F. and VII.G. of this preamble). They will not be discussed again here. The few remaining issues that are unique to landfills will be discussed below.

1. *Special Requirements for Ignitable or Reactive Wastes and for Incompatible Wastes (Sections 264.312 and 264.313).* Sections 264.312 and 264.313 are based upon the analogous Part 265 interim status standards. Section 265.312 was amended on June 29, 1981, and § 264.312 is based on the amended version. A discussion of the basis for the current restriction on landfilling ignitable and reactive wastes is set forth in the preamble to those standards at 46 FR 33402 (June 29, 1981).

2. *Special Requirements for Liquid Waste (Section 264.314).* Section 264.314 restricts the disposal of liquids in landfills. It is based upon the analogous Part 265 interim status standards, including portions which were recently promulgated on March 22, 1982 (47 FR 12316).

3. *Special Requirements for Containers (Section 264.315).* Section 264.315 provides that containers (except for very small containers) must be either (1) at least 90 percent full when placed in a landfill, or (2) crushed, shredded, or similarly reduced in volume to the maximum practical extent before burial in the landfill. The purpose of the rule is to minimize subsidence in the landfill resulting from decaying containers having void spaces.

The analogous interim status standard in § 265.315 provides only that an empty container must be crushed, etc., before placement in the landfill. However, it fails to define the term "empty" (and "full") and to address the subsidence that may be caused by the disposal of partially empty containers. Today's promulgation of § 264.315 (and the proposal of a parallel modification of § 265.315) addresses these regulatory gaps.

In the February 5, 1981 proposal, EPA proposed that to be considered full, containers have either 3 inches or less of void space or 10 percent or less volume of void space, whichever is less. Some commenters argued for less stringent numbers. Other commenters argued that crushing or shredding empty containers is impractical. These commenters did not provide EPA with data to support their comments.

The Agency believes that by allowing only full containers or those that have been crushed or otherwise reduced in void space to be placed in a landfill, disruptive subsidence of the final cover resulting from the placement of partially filled containers in landfills can be avoided. The Agency disagrees with the commenter who suggested that crushing or shredding empty containers is impractical. Several landfills are currently doing so and container crushing equipment is readily available.

Those owners or operators having containers which are partially filled may either (a) fill them to greater than 90 percent of their capacity, (b) empty them and then crush or shred them to the maximum extent practical, or, (c) to the extent technology and safety allow, reduce the volume of the partially full containers. The provision allowing landfilling of containers that are 90% full means that there could be about 4 inches of void space in the typical 55-gallon drum.

The Agency would prefer to set a performance limit on the required effectiveness of volume reduction and has considered imposing a requirement limiting maximum remaining void space after crushing to 10 percent of the precrushed volume. EPA presently lacks the data necessary to determine the practicality of such a limit. The Agency is, therefore, seeking comment, particularly from those currently crushing drums and those manufacturing crushing equipment, as to what numeric performance level may practically be required.

One commenter suggested that all containers which are so small that void spaces in them would not significantly affect the stability of a landfill should be allowed. The Agency agrees and is, therefore, exempting very small containers, such as an ampule.

4. *Disposal of Small Containers of Hazardous Waste in Overpacked Drums (Lab Packs) (Section 264.316).* Section 264.316 provides that small containers of hazardous wastes in overpacked drums, commonly known as "lab packs," may be placed in landfills if certain requirements are met. This provision allows disposal of ignitable or liquid wastes in drums in accordance with these special conditions. This regulation is based upon the recently promulgated interim status standard for lab packs (46 FR 56592, November 17, 1981).

Subpart N—Landfills

§ 264.300 Applicability.

The regulations in this subpart apply to owners and operators of facilities that dispose of hazardous waste in landfills, except as § 264.1 provides otherwise.

§ 264.301 Design and operating requirements.

(a) A landfill (except for an existing portion of a landfill) must have:

(1) A liner that is designed, constructed, and installed to prevent any migration of wastes out of the landfill to the adjacent subsurface soil or ground water or surface water at anytime during the active life (including the closure period) of the landfill. The liner must be constructed of materials that prevent wastes from passing into the liner during the active life of the facility. The liner must be:

(i) Constructed of materials that have appropriate chemical properties and sufficient strength and thickness to prevent failure due to pressure gradients (including static head and external hydrogeologic forces), physical contact with the waste or leachate to which they are exposed, climatic conditions, the stress of installation, and the stress of daily operation;

(ii) Placed upon a foundation or base capable of providing support to the liner and resistance to pressure gradients above and below the liner to prevent failure of the liner due to settlement, compression, or uplift; and

(iii) Installed to cover all surrounding earth likely to be in contact with the waste or leachate; and

(2) A leachate collection and removal system immediately above the liner that is designed, constructed, maintained, and operated to collect and remove leachate from the landfill. The Regional Administrator will specify design and operating conditions in the permit to ensure that the leachate depth over the liner does not exceed 30 cm (one foot). The leachate collection and removal system must be:

(i) Constructed of materials that are:

(A) Chemically resistant to the waste managed in the landfill and the leachate expected to be generated; and

(B) Of sufficient strength and thickness to prevent collapse under the pressures exerted by overlying wastes, waste cover materials, and by any equipment used at the landfill; and

(ii) Designed and operated to function without clogging through the scheduled closure of the landfill.

(b) The owner or operator will be exempted from the requirements of paragraph (a) of this section if the Regional Administrator finds, based on a demonstration by the owner or operator, that alternative design and operating practices, together with location characteristics, will prevent the migration of any hazardous constituents (see § 264.93) into the ground water or surface water at any future time. In deciding whether to grant an exemption, the Regional Administrator will consider:

(1) The nature and quantity of the wastes;

(2) The proposed alternate design and operation;

(3) The hydrogeologic setting of the facility, including the attenuative capacity and thickness of the liners and soils present between the landfill and ground water or surface water; and

(4) All other factors which would influence the quality and mobility of the leachate produced and the potential for it to migrate to ground water or surface water.

(c) The owner or operator must design, construct, operate, and maintain a run-on control system capable of preventing flow onto the active portion of the landfill during peak discharge from at least a 25-year storm.

(d) The owner or operator must design, construct, operate, and maintain a run-off management system to collect and control at least the water volume resulting from a 24-hour, 25-year storm.

(e) Collection and holding facilities (e.g., tanks or basins) associated with run-on and run-off control systems must be emptied or otherwise managed expeditiously after storms to maintain design capacity of the system.

(f) If the landfill contains any particulate matter which may be subject to wind dispersal, the owner or operator must cover or otherwise manage the landfill to control wind dispersal.

(g) The Regional Administrator will specify in the permit all design and operating practices that are necessary to ensure that the requirements of this section are satisfied.

§ 264.302 Double-lined landfills: Exemption from Subpart F ground-water protection requirements.

(a) The owner or operator of a double-lined landfill is not subject to regulation under Subpart F of this part if the following conditions are met:

(1) The landfill (including its underlying liners) must be located entirely above the seasonal high water table.

(2) The landfill must be underlain by two liners which are designed and constructed in a manner to prevent the migration of liquids into or out of the space between the liners. Both liners must meet all the specifications of § 264.301(a)(1).

(3) A leak detection system must be designed, constructed, maintained, and operated between the liners to detect any migration of liquid into the space between the liners.

(4) The landfill must have a leachate collection and removal system above the top liner that is designed, constructed, maintained, and operated in accordance with § 264.301(a)(2).

(b) If liquid leaks into the leak detection system, the owner or operator must:

(1) Notify the Regional Administrator of the leak in writing within seven days after detecting the leak; and

(2)(i) Within a period of time specified in the permit, remove accumulated liquid, repair or replace the liner which is leaking to prevent the migration of liquids through the liner, and obtain a certification from a qualified engineer that, to the best of his knowledge and opinion, the leak has been stopped; or

(ii) If a detection monitoring program pursuant to § 264.98 has already been established in the permit (to be complied with only if a leak occurs), begin to comply with that program and any other applicable requirements of Subpart F of this part within a period of time specified in the permit.

(c) The Regional Administrator will specify in the permit all design and operating practices that are necessary to ensure that the requirements of this section are satisfied.

§ 264.303 Monitoring and inspection.

(a) During construction or installation, liners (except in the case of existing portions of landfills exempt from § 264.301(a)) and cover systems (e.g., membranes, sheets, or coatings) must be inspected for uniformity, damage, and imperfections (*e.g.*, holes, cracks, thin spots, or foreign materials). Immediately after construction or installation:

(1) Synthetic liners and covers must be inspected to ensure tight seams and joints and the absence of tears, punctures, or blisters; and

(2) Soil-based and admixed liners and covers must be inspected for imperfections including lenses, cracks, channels, root holes, or other structural non-uniformities that may cause an increase in the permeability of the liner or cover.

(b) While a landfill is in operation, it must be inspected weekly and after storms to detect evidence of any of the following:

(1) Deterioration, malfunctions, or improper operation of run-on and run-off control systems;

(2) The presence of liquids in leak detection systems, where installed to comply with § 264.302;

(3) Proper functioning of wind dispersal control systems, where present; and

(4) The presence of leachate in and proper functioning of leachate collection and removal systems, where present.

§§ 264.304–264.308 [Reserved]

§ 264.309 Surveying and recordkeeping.

The owner or operator of a landfill must maintain the following items in the operating record required under § 264.73:

(a) On a map, the exact location and dimensions, including depth, of each cell with respect to permanently surveyed benchmarks; and

(b) The contents of each cell and the approximate location of each hazardous waste type within each cell.

§ 264.310 Closure and post-closure care.

(a) At final closure of the landfill or upon closure of any cell, the owner or operator must cover the landfill or cell with a final cover designed and constructed to:

(1) Provide long-term minimization of migration of liquids through the closed landfill;

(2) Function with minimum maintenance;

(3) Promote drainage and minimize erosion or abrasion of the cover;

(4) Accommodate settling and subsidence so that the cover's integrity is maintained; and

(5) Have a permeability less than or equal to the permeability of any bottom liner system or natural subsoils present.

(b) After final closure, the owner or operator must comply with all post-closure requirements contained in §§ 264.117–264.120, including maintenance and monitoring throughout the post-closure care period (specified in the permit under § 264.117). The owner or operator must:

(1) Maintain the integrity and effectiveness of the final cover, including making repairs to the cap as necessary to correct the effects of settling, subsidence, erosion, or other events;

(2) Maintain and monitor the leak detection system in accordance with § 264.302, where such a system is present between double liner systems;

(3) Continue to operate the leachate collection and removal system until leachate is no longer detected;

(4) Maintain and monitor the ground-water monitoring system and comply with all other applicable requirements of Subpart F of this Part;

(5) Prevent run-on and run-off from eroding or otherwise damaging the final cover; and

(6) Protect and maintain surveyed benchmarks used in complying with § 264.309.

(c) During the post-closure care period, if liquid leaks into a leak detection system installed under § 264.302, the owner or operator must notify the Regional Administrator of the leak in writing within seven days after detecting the leak. The Regional Administrator will modify the permit to require compliance with the requirements of Subpart F of this Part.

§ 264.311 [Reserved]

§ 264.312 Special requirements for ignitable or reactive waste.

(a) Except as provided in paragraph (b) of this section, and in § 264.316, ignitable or reactive waste must not be placed in a landfill, unless the waste is treated, rendered, or mixed before or immediately after placement in a landfill so that:

(1) The resulting waste, mixture, or dissolution of material no longer meets the definition of ignitable or reactive waste under §§ 261.21 or 261.23 of this Chapter; and

(2) Section 264.17(b) is complied with.

(b) Ignitable wastes in containers may be landfilled without meeting the requirements of paragraph (a) of this section, provided that the wastes are disposed of in such a way that they are protected from any material or conditions which may cause them to ignite. At a minimum, ignitable wastes must be disposed of in non-leaking containers which are carefully handled and placed so as to avoid heat, sparks, rupture, or any other condition that might cause ignition of the wastes; must be covered daily with soil or other non-combustible material to minimize the potential for ignition of the wastes; and must not be disposed of in cells that contain or will contain other wastes which may generate heat sufficient to cause ignition of the waste.

§ 264.313 Special requirements for incompatible wastes.

Incompatible wastes, or incompatible wastes and materials, (see Appendix V of this part for examples) must not be placed in the same landfill cell, unless § 264.17(b) is complied with.

§ 264.314 Special requirements for liquid waste.

(a) Bulk or non-containerized liquid waste or waste containing free liquids must not be placed in a landfill unless:

(1) The landfill has a liner and leachate collection and removal system that meet the requirements of § 264.301(a); or

(2) Before disposal, the liquid waste or waste containing free liquids is treated or stabilized, chemically or physically (e.g., by mixing with an absorbent solid), so that free liquids are no longer present.

(b) Containers holding free liquids must not be placed in a landfill unless:

(1) All free-standing liquid: (i) has been removed by decanting, or other methods; (ii) has been mixed with absorbent or solidified so that free-standing liquid is no longer observed; or (iii) has been otherwise eliminated; or

(2) The container is very small, such as an ampule; or

(3) The container is designed to hold free liquids for use other than storage, such as a battery or capacitor; or

(4) The container is a lab pack as defined in § 264.316 and is disposed of in accordance with § 264.316.

§ 264.315 Special requirements for containers.

Unless they are very small, such as an ampule, containers must be either:

(a) At least 90 percent full when placed in the landfill; or

(b) Crushed, shredded, or similarly reduced in volume to the maximum practical extent before burial in the landfill.

§ 264.316 Disposal of small containers of hazardous waste in overpacked drums (lab packs).

Small containers of hazardous waste in overpacked drums (lab packs) may be placed in a landfill if the following requirements are met:

(a) Hazardous waste must be packaged in non-leaking inside containers. The inside containers must be of a design and constructed of a material that will not react dangerously with, be decomposed by, or be ignited by the contained waste. Inside containers must be tightly and securely sealed. The inside containers must be of the size and type specified in the Department of Transportation (DOT) hazardous materials regulations (49 CFR Parts 173, 178, and 179), if those regulations specify a particular inside container for the waste.

(b) The inside containers must be overpacked in an open head DOT-specification metal shipping container (49 CFR Parts 178 and 179) of no more than 416-liter (110 gallon) capacity and surrounded by, at a minimum, a sufficient quantity of absorbent material to completely absorb all of the liquid contents of the inside containers. The metal outer container must be full after packing with inside containers and absorbent material.

(c) The absorbent material used must not be capable of reacting dangerously with, being decomposed by, or being ignited by the contents of the inside containers in accordance with § 264.17(b).

(d) Incompatible wastes, as defined in § 260.10 of this chapter, must not be placed in the same outside container.

(e) Reactive wastes, other than cyanide- or sulfide-bearing waste as defined in § 261.23(a)(5) of this chapter, must be treated or rendered non-reactive prior to packaging in accordance with paragraphs (a) through (d) of this section. Cyanide- and sulfide-bearing reactive waste may be packed in accordance with paragraphs (a) through (d) of this section without first being treated or rendered non-reactive.

§§ 264.317–264.339 [Reserved]

13. 40 CFR Part 264 is amended by adding Appendix IV to read as follows:

Appendix IV

Cochran's Approximation to the Behrens-Fisher Students' t-test

Using all the available background data (n_B readings), calculate the background mean (X_B) and background variance ($s_B{}^2$). For the single monitoring well under investigation (n_m reading), calculate the monitoring mean (X_m) and monitoring variance ($s_m{}^2$).

For any set of data ($X_1, X_2 \ldots X_n$) the mean is calculated by:

$$\overline{X} = \frac{X_1 + X_2 \ldots + X_n}{n}$$

and the variance is calculated by:

$$s^2 = \frac{(X_1 - \overline{X})^2 + (X_2 - \overline{X})^2 \ldots + (X_n - \overline{X})^2}{n-1}$$

where "n" denotes the number of observations in the set of data.

The t-test uses these data summary measures to calculate a t-statistic (t^*) and a comparison t-statistic (t_c). The t^* value is compared to the t_c value and a conclusion reached as to whether there has been a statistically significant change in any indicator parameter.

The t-statistic for all parameters except pH and similar monitoring parameters is:

$$t^* = \frac{X_m - \overline{X}_B}{\sqrt{\frac{s_m{}^2}{n_m} + \frac{s_B{}^2}{n_B}}}$$

If the value of this t-statistic is negative then there is no significant difference between the monitoring data and background data. It should be noted that significantly small negative values may be indicative of a failure of the assumption made for test validity or errors have been made in collecting the background data.

The t-statistic (t_c), against which t^* will be compared, necessitates finding t_B and t_m from standard (one-tailed) tables where,

t_B = t-tables with ($n_B - 1$) degrees of freedom, at the 0.05 level of significance.

t_m = t-tables with ($n_m - 1$) degrees of freedom, at the 0.05 level of significance.

Finally, the special weightings W_B and W_m are defined as:

$$W_B = \frac{s_B{}^2}{n_B} \quad \text{and} \quad W_m = \frac{s_m{}^2}{n_m}$$

and so the comparison t-statistic is:

$$t_c = \frac{W_B t_B + W_m t_m}{W_B + W_m}$$

The t-statistic (t^*) is now compared with the comparison t-statistic (t_c) using the following decision-rule:

If t^* *is equal to or larger than* t_c, then conclude that there most likely *has been a significant increase* in this specific parameter.

If t^* *is less than* t_c, then conclude that most likely *there has not been a change* in this specific parameter.

The t-statistic for testing pH and similar monitoring parameters is constructed in the same manner as previously described except the negative sign (if any) is discarded and the caveat concerning the negative value is ignored. The standard (two-tailed) tables are used in the construction t_c for pH and similar monitoring parameters.

If t^* is equal to or larger than t_c, then conclude that there most likely *has been a significant increase* (if the initial t^* had been negative, this would imply a significant decrease). If t^* is less than t_c, then conclude that there most likely has been no change.

A further discussion of the test may be found in *Statistical Methods* (6th Edition, Section 4.14) by G. W. Snedecor and W. G. Cochran, or *Principles and Procedures of Statistics* (1st Edition, Section 5.8) by R. G. D. Steel and J. H. Torrie.

STANDARD T-TABLES 0.05 LEVEL OF SIGNIFICANCE

Degrees of freedom	t-values (one-tail)	t-values (two-tail)
1	6.314	12.706
2	2.920	4.303
3	2.353	3.182
4	2.132	2.776
5	2.015	2.571
6	1.943	2.447
7	1.895	2.365
8	1.860	2.306
9	1.833	2.262
10	1.812	2.228
11	1.796	2.201
12	1.782	2.179
13	1.771	2.160
14	1.761	2.145
15	1.753	2.131
16	1.746	2.120
17	1.740	2.110
18	1.734	2.101
19	1.729	2.093
20	1.725	2.086
21	1.721	2.080
22	1.717	2.074
23	1.714	2.069
24	1.711	2.064
25	1.708	2.060
30	1.697	2.042
40	1.684	2.021

Adopted from Table III of "*Statistical Tables for Biological, Agricultural, and Medical Research*" (1947, R. A. Fisher and F. Yates).

10.5 RCRA PART 264 HAZARDOUS WASTE GROUNDWATER QUALITY MONITORING REGULATIONS (EXCERPT)

Subpart F—Ground-water Protection

264.90 Applicability.
264.91 Required programs.
264.92 Ground-water protection standard.
264.93 Hazardous constituents.
264.94 Concentration limits.
264.95 Point of compliance.
264.96 Compliance period.
264.97 General ground-water monitoring requirements.
264.98 Detection monitoring program.
264.99 Compliance monitoring program.
264.100 Corrective action program.
264.101–264.109 [Reserved]

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Subpart F—Ground-water Protection

§ 264.90 Applicability.

(a) Except as provided in paragraph (b) of this section, the regulations in this subpart apply to owners and operators of facilities that treat, store, or dispose of hazardous waste in surface impoundments, waste piles, land treatment units, or landfills. The owner or operator must satisfy the requirements of this subpart for all wastes (or constituents thereof) contained in any such waste management unit at the facility that receives hazardous waste after the effective date of this subpart (hereinafter referred to as a "regulated unit"). Any waste or waste constituent migrating beyond the waste management area under § 264.95(b) is assumed to originate from a regulated unit unless the Regional Administrator finds that such waste or waste constituent originated from another source.

(b) The owner or operator is not subject to regulation under this subpart if:

(1) He is exempted under § 264.1;

(2) He designs and operates a surface impoundment in compliance with § 264.222, a pile in compliance with § 264.250(c), § 264.252, or § 264.253, or a landfill in compliance with § 264.302;

(3) The Regional Administrator finds, pursuant to § 264.280(d), that the treatment zone of a land treatment unit does not contain levels of hazardous constituents that are above background levels of those constituents by an amount that is statistically significant, and if an unsaturated zone monitoring program meeting the requirements of § 264.278 has not shown a statistically significant increase in hazardous constituents below the treatment zone during the operating life of the unit. An exemption under this paragraph can only relieve an owner or operator of responsibility to meet the requirements of this subpart during the post-closure care period; or

(4) The Regional Administrator finds that there is no potential for migration of liquid from a regulated unit to the uppermost aquifer during the active life of the regulated unit (including the closure period) and the post-closure care period specified under § 264.117. This demonstration must be certified by a qualified geologist or geotechnical engineer. In order to provide an adequate margin of safety in the prediction of potential migration of liquid, the owner or operator must base any predictions made under this paragraph on assumptions that maximize the rate of liquid migration.

(c) The regulations under this subpart apply during the active life of the regulated unit (including the closure period). After closure of the regulated unit, the regulations in this subpart:

(1) Do not apply if all waste, waste residues, contaminated containment system components, and contaminated subsoils are removed or decontaminated at closure;

(2) Apply during the post-closure care period under § 264.117 if the owner or operator is conducting a detection monitoring program under § 264.98; or

(3) Apply during the compliance period under § 264.96 if the owner or operator is conducting a compliance monitoring program under § 264.99 or a corrective action program under § 264.100.

§ 264.91 Required programs.

(a) Owners and operators subject to this subpart must conduct a monitoring and response program as follows:

(1) Whenever hazardous constituents under § 264.93 from a regulated unit are detected at the compliance point under § 264.95, the owner or operator must institute a compliance monitoring program under § 264.99;

(2) Whenever the ground-water protection standard under § 264.92 is exceeded, the owner or operator must institute a corrective action program under § 264.100;

(3) Whenever hazardous constituents under § 264.93 from a regulated unit exceed concentration limits under § 264.94 in ground water between the compliance point under § 264.95 and the downgradient facility property boundary, the owner or operator must institute a corrective action program under § 264.100; or

(4) In all other cases, the owner or operator must institute a detection monitoring program under § 264.98.

(b) The Regional Administrator will specify in the facility permit the specific elements of the monitoring and response program. The Regional Administrator may include one or more of the programs identified in paragraph (a) of this section in the facility permit as may be necessary to protect human health and the environment and will specify the circumstances under which each of the programs will be required. In deciding whether to require the owner or operator to be prepared to institute a particular program, the Regional Administrator will consider the potential adverse effects on human health and the environment that might occur before final administrative action on a permit modification application to incorporate such a program could be taken.

§ 264.92 Ground-water protection standard.

The owner or operator must comply with conditions specified in the facility permit that are designed to ensure that hazardous constituents under § 264.93 entering the ground water from a regulated unit do not exceed the concentration limits under § 264.94 in the uppermost aquifer underlying the waste management area beyond the point of compliance under § 264.95 during the compliance period under § 264.96. The Regional Administrator will establish this ground-water protection standard in the facility permit when hazardous constituents have entered the ground water from a regulated unit.

§ 264.93 Hazardous constituents.

(a) The Regional Administrator will specify in the facility permit the hazardous constituents to which the ground-water protection standard of § 264.92 applies. Hazardous constituents are constituents identified in Appendix VIII of Part 261 of this chapter that have been detected in ground water in the uppermost aquifer underlying a regulated unit and that are reasonably expected to be in or derived from waste contained in a regulated unit, unless the Regional Administrator has excluded them under paragraph (b) of this section.

(b) The Regional Administrator will exclude an Appendix VIII constituent from the list of hazardous constituents specified in the facility permit if he finds that the constituent is not capable of posing a substantial present or potential hazard to human health or the environment. In deciding whether to grant an exemption, the Regional Administrator will consider the following:

(1) Potential adverse effects on ground-water quality, considering:

(i) The physical and chemical characteristics of the waste in the regulated unit, including its potential for migration;

(ii) The hydrogeological characteristics of the facility and surrounding land;

(iii) The quantity of ground water and the direction of ground-water flow;

(iv) The proximity and withdrawal rates of ground-water users;

(v) The current and future uses of ground water in the area;

(vi) The existing quality of ground water, including other sources of contamination and their cumulative impact on the ground-water quality;

(vii) The potential for health risks caused by human exposure to waste constituents;

(viii) The potential damage to wildlife, crops, vegetation, and physical structures caused by exposure to waste constituents;

(ix) The persistence and permanence of the potential adverse effects; and

(2) Potential adverse effects on hydraulically-connected surface water quality, considering:

(i) The volume and physical and chemical characteristics of the waste in the regulated unit;

(ii) The hydrogeological characteristics of the facility and surrounding land;

(iii) The quantity and quality of ground water, and the direction of ground-water flow;

(iv) The patterns of rainfall in the region;

(v) The proximity of the regulated unit to surface waters;

(vi) The current and future uses of surface waters in the area and any water quality standards established for those surface waters;

(vii) The existing quality of surface water, including other sources of contamination and the cumulative impact on surface water quality;

(viii) The potential for health risks caused by human exposure to waste constituents;

(ix) The potential damage to wildlife, crops, vegetation, and physical structures caused by exposure to waste constituents; and

(x) The persistence and permanence of the potential adverse effects.

(c) In making any determination under paragraph (b) of this section about the use of ground water in the area around the facility, the Regional Administrator will consider any identification of underground sources of drinking water and exempted aquifers made under § 122.35 of this chapter.

§ 264.94 Concentration limits.

(a) The Regional Administrator will specify in the facility permit concentration limits in the ground water for hazardous constituents established under § 264.93. The concentration of a hazardous constituent:

(1) Must not exceed the background level of that constituent in the ground water at the time that limit is specified in the permit; or

(2) For any of the constituents listed in Table 1, must not exceed the respective value given in that Table if the background level of the constituent is below the value given in Table 1; or

(3) Must not exceed an alternate limit established by the Regional Administrator under paragraph (b) of this section.

(b) The Regional Administrator will establish an alternate concentration limit for a hazardous constituent if he finds that the constituent will not pose a substantial present or potential hazard to human health or the environment as long as the alternate concentration limit is not exceeded. In establishing alternate concentration limits, the Regional Administrator will consider the following factors:

(1) Potential adverse effects on ground-water quality, considering:

TABLE 1.—MAXIMUM CONCENTRATION OF CONSTITUENTS FOR GROUND-WATER PROTECTION

Constituent	Maximum concentration [1]
Arsenic	0.05
Barium	1.0
Cadmium	0.01
Chromium	0.05
Lead	0.05
Mercury	0.002
Selenium	0.01
Silver	0.05
Endrin (1,2,3,4,10,10-hexachloro-1,7-epoxy-1,4,4a,5,6,7,8,9a-octahydro-1, 4-endo, endo-5,8-dimethano naphthalene)	0.0002
Lindane (1,2,3,4,5,6-hexachlorocyclohexane, gamma isomer)	0.004
Methoxychlor (1,1,1-Trichloro-2,2-bis (p-methoxyphenylethane)	0.1
Toxaphene (C_{10}—H_{10}—Cl_{6}, Technical chlorinated camphene, 67–69 percent chlorine)	0.005
2,4-D (2,4-Dichlorophenoxyacetic acid)	0.1
2,4,5-TP Silvex (2,4,5-Trichlorophenoxypropionic acid)	0.01

[1] Milligrams per liter.

(i) The physical and chemical characteristics of the waste in the regulated unit, including its potential for migration;

(ii) The hydrogeological characteristics of the facility and surrounding land;

(iii) The quantity of ground water and the direction of ground-water flow;

(iv) The proximity and withdrawal rates of ground-water users;

(v) The current and future uses of ground water in the area;

(vi) The existing quality of ground water, including other sources of contamination and their cumulative impact on the ground-water quality;

(vii) The potential for health risks caused by human exposure to waste constituents;

(viii) The potential damage to wildlife, crops, vegetation, and physical structures caused by exposure to waste constituents;

(ix) The persistence and permanence of the potential adverse effects; and

(2) Potential adverse effects on hydraulically-connected surface-water quality, considering:

(i) The volume and physical and chemical characteristics of the waste in the regulated unit;

(ii) The hydrogeological characteristics of the facility and surrounding land;

(iii) The quantity and quality of ground water, and the direction of ground-water flow;

(iv) The patterns of rainfall in the region;

(v) The proximity of the regulated unit to surface waters;

(vi) The current and future uses of surface waters in the area and any water quality standards established for those surface waters;

(vii) The existing quality of surface water, including other sources of contamination and the cumulative impact on surface-water quality;

(viii) The potential for health risks caused by human exposure to waste constituents;

(ix) The potential damage to wildlife, crops, vegetation, and physical structures caused by exposure to waste constituents; and

(x) The persistence and permanence of the potential adverse effects.

(c) In making any determination under paragraph (b) of this section about the use of ground water in the area around the facility the Regional Administrator will consider any identification of underground sources of drinking water and exempted aquifers made under § 122.35 of this chapter.

§ 264.95 Point of compliance.

(a) The Regional Administrator will specify in the facility permit the point of compliance at which the ground-water protection standard of § 264.92 applies and at which monitoring must be conducted. The point of compliance is a vertical surface located at the hydraulically downgradient limit of the waste management area that extends down into the uppermost aquifer underlying the regulated units.

(b) The waste management area is the limit projected in the horizontal plane of the area on which waste will be placed during the active life of a regulated unit.

(1) The waste management area includes horizontal space taken up by any liner, dike, or other barrier designed to contain waste in a regulated unit.

(2) If the facility contains more than one regulated unit, the waste management area is described by an imaginary line circumscribing the several regulated units.

§ 264.96 Compliance period.

(a) The Regional Administrator will specify in the facility permit the compliance period during which the ground-water protection standard of § 264.92 applies. The compliance period is the number of years equal to the active life of the waste management area (including any waste management activity prior to permitting, and the closure period.)

(b) The compliance period begins when the owner or operator initiates a compliance monitoring program meeting the requirements of § 264.99.

(c) If the owner or operator is engaged in a corrective action program at the end of the compliance period specified in paragraph (a) of this section, the compliance period is extended until the owner or operator can demonstrate that the ground-water protection standard of § 264.92 has not been exceeded for a period of three consecutive years.

§ 264.97 General ground-water monitoring requirements.

The owner or operator must comply with the following requirements for any ground-water monitoring program developed to satisfy § 264.98, § 264.99, or § 264.100:

(a) The ground-water monitoring system must consist of a sufficient number of wells, installed at appropriate locations and depths to yield ground-water samples from the uppermost aquifer that:

(1) Represent the quality of background water that has not been affected by leakage from a regulated unit; and

(2) Represent the quality of ground water passing the point of compliance.

(b) If a facility contains more than one regulated unit, separate ground-water monitoring systems are not required for each regulated unit provided that provisions for sampling the ground water in the uppermost aquifer will enable detection and measurement at the compliance point of hazardous constituents from the regulated units that have entered the ground water in the uppermost aquifer.

(c) All monitoring wells must be cased in a manner that maintains the integrity of the monitoring-well bore hole. This casing must be screened or perforated and packed with gravel or sand, where necessary, to enable collection of ground-water samples. The annular space (i.e., the space between the bore hole and well casing) above the sampling depth must be sealed to prevent contamination of samples and the ground water.

(d) The ground-water monitoring program must include consistent sampling and analysis procedures that are designed to ensure monitoring results that provide a reliable indication of ground-water quality below the waste management area. At a minimum the program must include procedures and techniques for:

(1) Sample collection;

(2) Sample preservation and shipment;

(3) Analytical procedures; and

(4) Chain of custody control.

(e) The ground-water monitoring program must include sampling and analytical methods that are appropriate for ground-water sampling and that accurately measure hazardous constituents in ground-water samples.

(f) The ground-water monitoring program must include a determination of the ground-water surface elevation each time ground water is sampled.

(g) Where appropriate, the ground-water monitoring program must establish background ground-water quality for each of the hazardous constituents or monitoring parameters or constituents specified in the permit.

(1) In the detection monitoring program under § 264.98, background ground-water quality for a monitoring parameter or constituent must be based on data from quarterly sampling of wells upgradient from the waste management area for one year.

(2) In the compliance monitoring program under § 264.99, background ground-water quality for a hazardous constituent must be based on data from upgradient wells that:

(i) Is available before the permit is issued;

(ii) Accounts for measurement errors in sampling and analysis; and

(iii) Accounts, to the extent feasible, for seasonal fluctuations in background ground-water quality if such fluctuations are expected to affect the concentration of the hazardous constituent.

(3) Background quality may be based on sampling of wells that are not upgradient from the waste management area where:

(i) Hydrogeologic conditions do not allow the owner or operator to determine what wells are upgradient; or

(ii) Sampling at other wells will provide an indication of background ground-water quality that is as representative or more representative than that provided by the upgradient wells.

(4) In developing the data base used to determine a background value for each parameter or constituent, the owner or operator must take a minimum of one sample from each well and a minimum of four samples from the entire system used to determine background ground-water quality, each time the system is sampled.

(h) The owner or operator must use the following statistical procedure in determining whether background values or concentration limits have been exceeded:

(1) If, in a detection monitoring program, the level of a constituent at the compliance point is to be compared to the constituent's background value and that background value has a sample coefficient of variation less than 1.00:

(i) The owner or operator must take at least four portions from a sample at each well at the compliance point and determine whether the difference between the mean of the constituent at each well (using all portions taken) and the background value for the constituent is significant at the 0.05 level using the Cochran's Approximation to the Behrens-Fisher Student's t-test as described in Appendix IV of this part. If the test indicates that the difference is significant, the owner or operator must repeat the same procedure (with at least the same number of portions as used in the first test) with a fresh sample from the monitoring well. If this second round of analyses indicates that the difference is significant, the owner or operator must conclude that a statistically significant change has occurred; or

(ii) The owner or operator may use an equivalent statistical procedure for determining whether a statistically significant change has occurred. The Regional Administrator will specify such a procedure in the facility permit if he finds that the alternative procedure reasonably balances the probability of falsely identifying a non-contaminating regulated unit and the probability of failing to identify a contaminating regulated unit in a manner that is comparable to that of the statistical procedure described in paragraph (h)(1)(i) of this section.

(2) In all other situations in a detection monitoring program and in a compliance monitoring program, the owner or operator must use a statistical procedure providing reasonable confidence that the migration of hazardous constituents from a regulated unit into and through the aquifer will be indicated. The Regional Administrator will specify a statistical procedure in the facility permit that he finds:

(i) Is appropriate for the distribution of the data used to establish background values or concentration limits; and

(ii) Provides a reasonable balance between the probability of falsely identifying a non-contaminating regulated unit and the probability of failing to identify a contaminating regulated unit.

§ 264.98 Detection monitoring program.

An owner or operator required to establish a detection monitoring program under this subpart must, at a minimum, discharge the following responsibilities:

(a) The owner or operator must monitor for indicator parameters (e.g., specific conductance, total organic carbon, or total organic halogen), waste constituents, or reaction products that provide a reliable indication of the presence of hazardous constituents in ground water. The Regional Administrator will specify the parameters or constituents to be monitored in the facility permit, after considering the following factors:

(1) The types, quantities, and concentrations of constituents in wastes managed at the regulated unit;

(2) The mobility, stability, and persistance of waste constituents or their reaction products in the unsaturated zone beneath the waste management area;

(3) The detectability of indicator parameters, waste constituents, and reaction products in ground water; and

(4) The concentrations or values and coefficients of variation of proposed monitoring parameters or constituents in the ground-water background.

(b) The owner or operator must install a ground-water monitoring system at the compliance point as specified under § 264.95. The ground-water monitoring system must comply with § 264.97(a)(2), (b), and (c).

(c) The owner or operator must establish a background value for each monitoring parameter or constituent specified in the permit pursuant to paragraph (a) of this section. The permit will specify the background values for each parameter or specify the procedures to be used to calculate the background values.

(1) The owner or operator must comply with § 264.97(g) in developing the data base used to determine background values.

(2) The owner or operator must express background values in a form necessary for the determination of statistically significant increases under § 264.97(h).

(3) In taking samples used in the determination of background values, the owner or operator must use a ground-water monitoring system that complies with § 264.97(a)(1), (b), and (c).

(d) The owner or operator must determine ground-water quality at each monitoring well at the compliance point at least semi-annually during the active life of a regulated unit (including the closure period) and the post-closure care period. The owner or operator must express the ground-water quality at each monitoring well in a form necessary for the determination of statistically significant increases under § 264.97(h).

(e) The owner or operator must determine the ground-water flow rate and direction in the uppermost aquifer at least annually.

(f) The owner or operator must use procedures and methods for sampling and analysis that meet the requirements of § 264.97 (d) and (e).

(g) The owner or operator must determine whether there is a statistically significant increase over background values for any parameter or constituent specified in the permit pursuant to paragraph (a) of this section each time he determines ground-water quality at the compliance point under paragraph (d) of this section.

(1) In determining whether a statistically significant increase has occurred, the owner or operator must compare the ground-water quality at each monitoring well at the compliance point for each parameter or constituent to the background value for that parameter or constituent, according to the statistical procedure specified in the permit under § 264.97(h).

(2) The owner or operator must determine whether there has been a statistically significant increase at each monitoring well at the compliance point within a reasonable time period after completion of sampling. The Regional Administrator will specify that time period in the facility permit, after considering the complexity of the statistical test and the availability of laboratory facilities to perform the analysis of ground-water samples.

(h) If the owner or operator determines, pursuant to paragraph (g) of this section, that there is a statistically significant increase for parameters or constituents specified pursuant to paragraph (a) of this section at any monitoring well at the compliance point, he must:

(1) Notify the Regional Administrator of this finding in writing within seven days. The notification must indicate what parameters or constituents have shown statistically significant increases;

(2) Immediately sample the ground water in all monitoring wells and determine the concentration of all constituents identified in Appendix VIII of Part 261 of this chapter that are present in ground water;

(3) Establish a background value for each Appendix VIII constituent that has been found at the compliance point under paragraph (h)(2) of this section, as follows:

(i) The owner or operator must comply with § 264.97(g) in developing the data base used to determine background values;

(ii) The owner or operator must express background values in a form necessary for the determination of statistically significant increases under § 264.97(h); and

(iii) In taking samples used in the determination of background values, the owner or operator must use a ground-water monitoring system that complies with § 264.97(a)(1), (b), and (c);

(4) Within 90 days, submit to the Regional Administrator an application for a permit modification to establish a compliance monitoring program meeting the requirements of § 264.99. The application must include the following information:

(i) An identification of the concentration of any Appendix VIII constituents found in the ground water at each monitoring well at the compliance point;

(ii) Any proposed changes to the ground-water monitoring system at the facility necessary to meet the requirements of § 264.99;

(iii) Any proposed changes to the monitoring frequency, sampling and analysis procedures or methods, or statistical procedures used at the facility necessary to meet the requirements of § 264.99;

(iv) For each hazardous constituent found at the compliance point, a proposed concentration limit under § 264.94(a)(1) or (2), or a notice of intent to seek a variance under § 264.94(b); and

(5) Within 180 days, submit to the Regional Administrator:

(i) All data necessary to justify any variance sought under § 264.94(b); and

(ii) An engineering feasibility plan for a corrective action program necessary to meet the requirements of § 264.100, unless:

(A) All hazardous constituents identified under paragraph (h)(2) of this section are listed in Table 1 of § 264.94 and their concentrations do not exceed the respective values given in that Table; or

(B) The owner or operator has sought a variance under § 264.94(b) for every hazardous constituent identified under paragraph (h)(2) of this section.

(i) If the owner or operator determines, pursuant to paragraph (g) of this section, that there is a statistically significant increase of parameters or consitutents specified pursuant to paragraph (a) of this section at any monitoring well at the compliance point, he may demonstrate that a source other than a regulated unit caused the increase or that the increase resulted from error in sampling, analysis, or evaluation. While the owner or operator may make a demonstration under this paragraph in addition to, or in lieu of, submitting a permit modification application under paragraph (h)(4) of this section, he is not relieved of the requirement to submit a permit modification application within the time specified in paragraph (h)(4) of this section unless the demonstration made under this paragraph successfully shows that a source other than a regulated unit caused the increase or that the increase resulted from error in sampling, analysis, or evaluation. In making a demonstration under this paragraph, the owner or operator must:

(1) Notify the Regional Administrator in writing within seven days of determining a statistically significant increase at the compliance point that he intends to make a demonstration under this paragraph;

(2) Within 90 days, submit a report to the Regional Administrator which demonstrates that a source other than a regulated unit caused the increase, or that the increase resulted from error in sampling, analysis, or evaluation;

(3) Within 90 days, submit to the Regional Administrator an application for a permit modification to make any appropriate changes to the detection monitoring program at the facility; and

(4) Continue to monitor in accordance with the detection monitoring program established under this section.

(j) If the owner or operator determines that the detection monitoring program no longer satisfies the requirements of this section, he must, within 90 days, submit an application for a permit modification to make any appropriate changes to the program.

(k) The owner or operator must assure that monitoring and corrective action measures necessary to achieve compliance with the ground-water protection standard under § 264.92 are taken during the term of the permit.

§ 264.99 Compliance monitoring program.

An owner or operator required to establish a compliance monitoring program under this subpart must, at a minimum, discharge the following responsibilities:

(a) The owner or operator must monitor the ground water to determine whether regulated units are in compliance with the ground-water protection standard under § 264.92. The Regional Administrator will specify the ground-water protection standard in the facility permit, including:

(1) A list of the hazardous constituents identified under § 264.93;

(2) Concentration limits under § 264.94 for each of those hazardous constituents;

(3) The compliance point under § 264.95; and

(4) The compliance period under § 264.96.

(b) The owner or operator must install a ground-water monitoring system at the compliance point as specified under § 264.95. The ground-water monitoring system must comply with § 264.97(a)(2), (b), and (c).

(c) Where a concentration limit established under paragraph (a)(2) of this section is based on background ground-water quality, the Regional Administrator will specify the concentration limit in the permit as follows:

(1) If there is a high temporal correlation between upgradient and compliance point concentrations of the hazardous constitutents, the owner or operator may establish the concentration limit through sampling at upgradient wells each time ground water is sampled at the compliance point. The Regional Administrator will specify the procedures used for determining the concentration limit in this manner in the permit. In all other cases, the concentration limit will be the mean of the pooled data on the concentration of the hazardous constituent.

(2) If a hazardous constituent is identified on Table 1 under § 264.94 and the difference between the respective concentration limit in Table 1 and the background value of that constituent under § 264.97(g) is not statistically significant, the owner or operator must use the background value of the constituent as the concentration limit. In determining whether this difference is statistically significant, the owner or operator must use a statistical procedure providing reasonable confidence that a real difference will be indicated. The statistical procedure must:

(i) Be appropriate for the distribution of the data used to establish background values; and

(ii) Provide a reasonable balance between the probability of falsely identifying a significant difference and the probability of failing to identify a significant difference.

(3) The owner or operator must:

(i) Comply with § 264.97(g) in developing the data base used to determine background values;

(ii) Express background values in a form necessary for the determination of statistically significant increases under § 264.97(h); and

(iii) Use a ground-water monitoring system that complies with § 264.97(a)(1), (b), and (c).

(d) The owner or operator must determine the concentration of hazardous constituents in ground water at each monitoring well at the compliance point at least quarterly during the compliance period. The owner or operator must express the concentration at each monitoring well in a form necessary for the determination of statistically significant increases under § 264.97(h).

(e) The owner or operator must determine the ground-water flow rate and direction in the uppermost aquifer at least annually.

(f) The owner or operator must analyze samples from all monitoring wells at the compliance point for all constituents contained in Appendix VIII of Part 261 of this chapter at least annually to determine whether additional hazardous constituents are present in the uppermost aquifer. If the owner or operator finds Appendix VIII constituents in the ground water that are not identified in the permit as hazardous constituents, the owner or operator must report the concentrations of these additional constituents to the Regional Administrator within seven days after completion of the analysis.

(g) The owner or operator must use procedures and methods for sampling and analysis that meet the requirements of § 264.97(d) and (e).

(h) The owner or operator must determine whether there is a statistically significant increase over the concentration limits for any hazardous constituents specified in the permit pursuant to paragraph (a) of this section each time he determines the concentration of hazardous constituents in ground water at the compliance point.

(1) In determining whether a statistically significant increase has occurred, the owner or operator must compare the ground-water quality at each monitoring well at the compliance point for each hazardous constituent to the concentration limit for that constituent according to the statistical procedures specified in the permit under § 264.97(h).

(2) The owner or operator must determine whether there has been a statistically significant increase at each monitoring well at the compliance point, within a reasonable time period after completion of sampling. The Regional Administrator will specify that time period in the facility permit, after considering the complexity of the statistical test and the availability of laboratory facilities to perform the analysis of ground-water samples.

(i) If the owner or operator determines, pursuant to paragraph (h) of this section, that the ground-water protection standard is being exceeded at any monitoring well at the point of compliance, he must:

(1) Notify the Regional Administrator of this finding in writing within seven days. The notification must indicate what concentration limits have been exceeded.

(2) Submit to the Regional Administrator an application for a permit modification to establish a corrective action program meeting the requirements of § 264.100 within 180 days, or within 90 days if an engineering feasibility study has been previously submitted to the Regional Administrator under § 264.98(h)(5). The application must at a minimum include the following information:

(i) A detailed description of corrective actions that will achieve compliance with the ground-water protection standard specified in the permit under paragraph (a) of this section; and

(ii) A plan for a ground-water monitoring program that will demonstrate the effectiveness of the corrective action. Such a ground-water monitoring program may be based on a compliance monitoring program developed to meet the requirements of this section.

(j) If the owner or operator determines, pursuant to paragraph (h) of this section, that the ground-water protection standard is being exceeded at any monitoring well at the point of compliance, he may demonstrate that a source other than a regulated unit caused the increase or that the increase resulted from error in sampling, analysis or evaluation. While the owner or operator may make a demonstration under this paragraph in addition to, or in lieu of, submitting a permit modification application under paragraph (i)(2) of this section, he is not relieved of the requirement to submit a permit modification application within the time specified in paragraph (i)(2) of this section unless the demonstration made under this paragraph successfully shows that a source other than a regulated unit caused the increase or that the increase resulted from error in sampling, analysis, or evaluation. In making a demonstration under this paragraph, the owner or operator must:

(1) Notify the Regional Administrator in writing within seven days that he intends to make a demonstration under this paragraph;

(2) Within 90 days, submit a report to the Regional Administrator which demonstrates that a source other than a regulated unit caused the standard to be exceeded or that the apparent noncompliance with the standards resulted from error in sampling, analysis, or evaluation;

(3) Within 90 days, submit to the Regional Administrator an application for a permit modification to make any appropriate changes to the compliance monitoring program at the facility; and

(4) Continue to monitor in accord with the compliance monitoring program established under this section.

(k) If the owner or operator determines that the compliance monitoring program no longer satisfies the requirements of this section, he must, within 90 days, submit an application for a permit modification to make any appropriate changes to the program.

(l) The owner or operator must assure that monitoring and corrective action measures necessary to achieve compliance with the ground-water protection standard under § 264.92 are taken during the term of the permit.

§ 264.100 Corrective action program.

An owner or operator required to establish a corrective action program under this subpart must, at a minimum, discharge the following responsibilities:

(a) The owner or operator must take corrective action to ensure that regulated units are in compliance with the ground-water protection standard under § 264.92. The Regional Administrator will specify the ground-water protection standard in the facility permit, including:

(1) A list of the hazardous constituents identified under § 264.93;

(2) Concentration limits under § 264.94 for each of those hazardous constituents;

(3) The compliance point under § 264.95; and

(4) The compliance period under § 264.96.

(b) The owner or operator must implement a corrective action program that prevents hazardous constituents from exceeding their respective concentration limits at the compliance point by removing the hazardous waste constituents or treating them in place. The permit will specify the specific measures that will be taken.

(c) The owner or operator must begin corrective action within a reasonable time period after the ground-water protection standard is exceeded. The Regional Administrator will specify that time period in the facility permit. If a facility permit includes a corrective action program in addition to a compliance monitoring program, the permit will specify when the corrective action will begin and such a requirement will operate in lieu of § 264.99(i)(2).

(d) In conjunction with a corrective action program, the owner or operator must establish and implement a ground-water monitoring program to demonstrate the effectiveness of the corrective action program. Such a monitoring program may be based on the requirements for a compliance monitoring program under § 264.99 and must be as effective as that program in determining compliance with the ground-water protection standard under § 264.92 and in determining the success of a corrective action program under paragraph (e) of this section, where appropriate.

(e) In addition to the other requirements of this section, the owner or operator must conduct a corrective action program to remove or treat in place any hazardous constituents under § 264.93 that exceed concentration limits under § 264.94 in ground water between the compliance point under § 264.95 and the downgradient facility property boundary. The permit will specify the measures to be taken.

(1) Corrective action measures under this paragraph must be initiated and completed within a reasonable period of time considering the extent of contamination.

(2) Corrective action measures under this paragraph may be terminated once the concentration of hazardous constituents under § 264.93 is reduced to levels below their respective concentration limits under § 264.94.

(f) The owner or operator must continue corrective action measures during the compliance period to the extent necessary to ensure that the ground-water protection standard is not exceeded. If the owner or operator is conducting corrective action at the end of the compliance period, he must continue that corrective action for as long as necessary to achieve compliance with the ground-water protection standard. The owner or operator may terminate corrective action measures taken beyond the period equal to the active life of the waste management area (including the closure period) if he can demonstrate, based on data from the ground-water monitoring program under paragraph (d) of this section, that the ground-water protection standard of § 264.92 has not been exceeded for a period of three consecutive years.

(g) The owner or operator must report in writing to the Regional Administrator on the effectiveness of the corrective action program. The owner or operator must submit these reports semi-annually.

(h) If the owner or operator determines that the corrective action program no longer satisfies the requirements of this section, he must, within 90 days, submit an application for a permit modification to make any appropriate changes to the program.

§§ 264.101–264.109 [Reserved]

9. In 40 CFR Part 264, Subpart G, § 264.110 is amended by revising paragraph (b), § 264.112 is amended by revising paragraphs (a), introductory text, and (a)(1), § 264.117 is amended by revising paragraphs (a)(1)(i) and (ii), and § 264.118 is amended by revising paragraph (a), introductory text, (a)(1), (2)(i) and (ii) to read as follows:

§ 264.110 Applicability.

* * * * *

(b) Sections 264.117–264.120 (which concern post-closure care) apply to the owners and operators of:

(1) All hazardous waste disposal facilities; and

(2) Piles, and surface impoundments from which the owner or operator intends to remove the wastes at closure, to the extent that these sections are made applicable to such facilities in §§ 264.228 and 264.258.

§ 264.112 Closure plan; amendment of plan.

(a) The owner or operator of a hazardous waste management facility must have a written closure plan. The plan must be submitted with the permit application, in accordance with § 122.25(a)(13) of this chapter, and approved by the Regional Administrator as part of the permit issuance proceeding under Part 124 of this chapter. In accordance with § 122.29 of this chapter, the approved closure plan will become a condition of any RCRA permit. The Regional Administrator's decision must assure that that approved closure plan is consistent with §§ 264.111, 264.113, 264.114, 264.115, and the applicable requirements of §§ 264.178, 264.197, 264.228, 264.258, 264.280, 264.310, and 264.351. A copy of the approved plan and all revisions to the plan must be kept at the facility until closure is completed and certified in accordance with § 264.115. The plan must identify steps necessary to completely or partially close the facility at any point during its intended operating life and to completely close the facility at the end of its intended operating life. The closure plan must include, at least:

(1) A description of how and when the facility will be partially closed, if applicable, and finally closed. The description must identify the maximum extent of the operation which will be unclosed during the life of the facility, and how the requirements of §§ 264.111, 264.113, 264.114, 264.115, and the applicable closure requirements of §§ 264.178, 264.197, 264.228, 264.258, 264.280, 264.310, and 264.351 will be met;

* * * * *

§ 264.117 Post-closure care and use of property.

(a)(1) * * *

(i) Monitoring and reporting in accordance with the requirements of Subparts F, K, L, M, and N of this part; and

(ii) Maintenance and monitoring of waste containment systems in accordance with the requirements of Subparts F, K, L, M, and N of this part.

* * * * *

§ 264.118 Post-closure plan; amendment of plan.

(a) The owner or operator of a disposal facility must have a written post-closure plan. In addition, certain piles and certain surface impoundments from which the owner or operator intends to remove the wastes at closure are required by §§ 264.228 and 264.258 to have post-closure plans. The plan must be submitted with a permit application, in accordance with § 122.25(a)(13) of this chapter, and approved by the Regional Administrator as part of the permit issuance proceeding under Part 124 of this chapter. In accordance with §122.29 of this chapter, the approved post-closure plan will become a condition of any permit issued. A copy of the approved plan and all revisions to the plan must be kept at the facility until the post-closure care period begins. This plan must identify the activities that will be carried on after closure and the frequency of these activities, and include at least:

(1) A description of the planned monitoring activities and frequencies at which they will be performed to comply

with Subparts F, K, L, M, and N of this part during the post-closure care period;

(2) * * *

(i) The intergrity of the cap and final cover or other containment systems in accordance with the requirements of Subparts K, L, M, and N of this part; and

(ii) The function of the facility monitoring equipment in accordance with the requirements of Subparts F, K, L, M, and N of this part; and

* * * * *

10. In 40 CFR Part 264, Subpart H, § 264.144 is amended by revising paragraph (b); § 264.142 is amended by revising paragraph (a), except for the comment; § 264.144 is amended by revising paragraph (a); and § 264.145 is amended by revising the undesignated paragraph preceding paragraph (a) to read as follows:

§ 264.140 Applicability.

* * * * *

(b) The requirements of §§ 264.144 and 264.145 apply only to owners and operators of:

(1) Disposal facilities, and

(2) Piles, and surface impoundments from which the owner or operator intends to remove the wastes at closure, to the extent that these sections are made applicable to such facilities in §§ 264.228 and 264.258.

* * * * *

§ 264.142 Cost estimate for closure.

(a) The owner or operator must have a written estimate, in current dollars, of the cost of closing the facility in accordance with the requirements in §§ 264.111–264.115 and applicable closure requirements in §§ 264.178, 264.197, 264.228, 264.258, 264.280, 264.310, and 264.351. The estimate must equal the cost of closure at the point in the facility's operating life when the extent and manner of its operation would make closure the most expensive, as indicated by its closure plan (see § 264.112(a)).

* * * * *

§ 264.144 Cost estimate for post-closure care.

(a) The owner or operator of a facility subject to post-closure monitoring or maintenance requirements must have a written estimate, in current dollars, of the annual cost of post-closure monitoring and maintenance of the facility in accordance with the applicable post-closure regulations in §§ 264.117–264.120, 264.228, 264.258, 264.280, and 264.310. The post-closure cost estimate is calculated by multiplying the annual post-closure cost estimate by the number of years of post-closure care required under Subpart G of Part 264.

* * * * *

§ 264.145 Financial assurance for post-closure care.

The owner or operator of a facility subject to post-closure monitoring or maintenance requirements must establish financial assurance for post-closure care in accordance with the approved post-closure plan for the facility. He must choose from the following options:

* * * * *

10.6 RCRA PART 264 HAZARDOUS WASTE LAND TREATMENT REGULATIONS (EXCERPT)

Subpart M—Land Treatment

264.270 Applicability.
264.271 Treatment program.
264.272 Treatment demonstration.
264.273 Design and operating requirements.
264.274–264.275 [Reserved]
264.276 Food-chain crops.
264.277 [Reserved]
264.278 Unsaturated zone monitoring.
264.279 Recordkeeping.
264.280 Closure and post-closure care.
264.281 Special requirements for ignitable or reactive waste.
264.282 Special requirements for incompatible wastes.
264.283–264.299 [Reserved]

H. Land Treatment (Part 264, Subpart M)

EPA believes that land treatment can be a viable management practice for treating and disposing of some types of hazardous wastes. Land treatment involves the application of waste on the soil surface or the incorporation of waste into the upper layers of the soil in order to degrade, transform or immobilize hazardous constituents present in hazardous waste. The success of land treatment particularly depends upon the operational management of the units. Unlike many landfills or surface impoundments, for example, land treatment does not use highly impermeable liners to contain wastes. Rather, land treatment relies on the dynamic physical, chemical, and biological processes occurring in the upper layers of the soil for the degradation, transformation, and immobilization of hazardous constituents. In this sense, land treatment can be viewed as an "open" system.

Because land treatment depends upon a number of soil/waste interactions for success, it is especially important that the units be carefully operated. Maintenance of proper soil pH to optimize microbial action and metal immobilization, careful management of waste application rate to prevent exceeding the soil's treatment capacity, and control of surface water run-off to prevent untreated hazardous waste from leaving the facility are several of the key operational aspects. In addition, well-managed land treatment includes monitoring in the unsaturated zone to provide information that the owner or operator will use in modifying his operating practices to maximize the success of treatment processes.

As described in other sections of this preamble, one of the principal objectives of the design and operating requirements applicable to each type of unit is to provide effective management of liquids at the facility to minimize the risk of ground-water contamination. At surface impoundments, landfills and piles this objective is principally served by the construction of barriers that prevent liquids from entering the units and from entering the soil.

The general approach must be modified somewhat for land treatment units. Land treatment units are dissimilar to other land disposal units in that they are not designed and operated to minimize *all* releases to ground water. On the contrary, they are open systems that freely allow liquid to move out of the unit. The goal of land treatment, therefore, is to reduce the hazardousness of waste applied in or on the soil through degradation, transformation and immobilization processes.

The land treatment regulatory approach, however, does seek to minimize the uncontrolled migration of hazardous constituents into the environment. This is accomplished by using a defined layer of surface and subsurface soils (referred to as the "treatment zone") to degrade, transform or immobilize the hazardous constituents contained in the leachate passing through the system. Such treatment processes achieve the same general objectives as the liquids management strategy used at other types of land disposal in that they act to prevent hazardous constituents from migrating into the environment.

1. *Applicability (Section 264.270).* The regulations in this Subpart apply to owners and operators of new and existing land treatment units. There is no exemption for "existing portions" as found in the regulations for other types of land disposal. The requirements for land treatment units do not require the placement of liners under the waste and, thus, should not pose major retrofitting problems for existing portions.

2. *Treatment Program (Section 264.271).* The key element of a land treatment unit is the program which the owner or operator establishes to degrade, transform or immobilize the hazardous constituents in the wastes managed at the unit. Today's regulations indicate that there are three principal elements to the treatment program that will be specified in the facility permit. First, the permit will specify the wastes that may be handled at the unit. (The Regional Administrator will base his selection of the wastes allowed at the unit on the treatment demonstration under § 264.272.) EPA is concerned that parties who engage in uncontrolled dumping of waste not be allowed to claim that they are conducting a land treatment operation simply because some breakdown of waste constituents occurs when the waste is dumped. Therefore, EPA believes that land treatment should be reserved for those hazardous wastes having hazardous constituents that can be completely degraded, transformed, or immobilized through land treatment.

At present, the Agency believes that land treatment should be confined to wastes that are primarily organic and that can be greatly reduced in volume by physical, chemical, and biological decomposition in surface soils. The Agency also believes that the smaller inorganic or persistent organic fractions of these wastes can also be effectively treated in surface soils. Hazardous constituents such as heavy metals and persistent organic compounds are either unaffected or are only slowly affected by the primary treatment mechanisms—degradation and transformation. Instead, these hazardous constituents can be treated by immobilization in surface soils.

Effective immobilization of hazardous constituents at land treatment units can occur through chemical or physical processes. Hazardous constituents may be effectively immobilized via chemical reactions, such as precipitation, complexation, and cation exchange reactions, or via physical attenuation processes which entrap hazardous constituents within the soil matrix.

Dilution, however, does not constitute an acceptable treatment process. Dilution does not provide chemical, biological, or physical "treatment" (i.e., degradation, transformation or immobilization) of hazardous constituents. Rather, dilution allows wide dispersal of hazardous constituents in the soil matrix. Since they remain untreated, such constituents may eventually migrate and concentrate to unacceptable levels in ground water or surface water.

Second, the land treatment program will include a set of design and operating measures that are necessary to maximize degradation, transformation and immobilization of hazardous waste constituents. (The Regional Administrator will also base his selection of these design and operating conditions on the treatment demonstration under § 264.272.)

The waste application rate and the timing of such applications are two of the most important elements of a program for managing a land treatment unit. The Regional Administrator will, therefore, explicitly address these two factors in the facility permit. Another critical factor is pH control. Soil pH has a major influence on the magnitude of microflora populations, which are essential for degradation, and on the mobility of metals. There are many unit-specific operations that will be necessary to achieve the intended performance, such as proper tilling frequencies, maintenance of microbial populations (perhaps by the addition of fertilizers), and careful management of the water content of the treatment zone. These specifics of unit operation will also be addressed in the facility permit.

Third, the treatment program will include an unsaturated zone monitoring program. The purpose of this program is to determine the success of treatment in the treatment zone. The information provided by this monitoring will help in making modifications to the operating practices at the unit to maximize the success of treatment. Thus, the purpose of the monitoring is to assist in "fine-tuning" the land treatment program. The elements of the unsaturated zone monitoring program will be discussed in more detail later in this preamble.

As part of the development of the land treatment program, the Regional Administrator will define a list of hazardous constituents that are of concern. These are the constituents that the owner or operator must seek to degrade, transform or immobilize. As in Subpart F, the basic universe from which hazardous constituents are selected is the list of constituents in Appendix VIII of Part 261. (The preamble discussion of Subpart F explains the basic rationale for using Appendix VIII).

In the land treatment regulations, the hazardous constituents are those Appendix VIII constituents that are reasonably expected to be in, or derived from, waste placed in or on the treatment zone. The owner or operator must assist in establishing what the hazardous constituents will be at the facility by conducting a thorough waste analysis of the wastes that will be handled at the facility. (This step is required under the general waste analysis provision of § 264.13 because such information is necessary to ensure compliance with Subpart M.) It may be possible to develop waste analysis procedures that attempt to characterize broad classes of waste; if so, it will not be necessary to analyze each batch of waste that might be handled at the unit.

Another basic element of the treatment program is a clear definition of the treatment zone, the portion of the unsaturated zone in which the owner or operator intends to accomplish degradation, transformation and immobilization of hazardous constituents. The Regional Administrator will specify the vertical and horizontal dimensions of the treatment zone.

One of the crucial concerns about the treatment zone is its depth. EPA considered several options for defining the appropriate depth of the treatment zone. One option was to make the treatment zone the "zone of incorporation." (This was the approach included in the February 5, 1981 proposed rules.) Commenters pointed out, however, that liquid hazardous wastes are sometimes spread on the surface of the soil and thus are not incorporated. In such cases a "zone of incorporation" is not a meaningful concept. Therefore, EPA decided not to use this approach.

A second option was to let the owner or operator define the treatment zone as long as it was above the water table. While this approach had the advantage of flexibility, EPA was concerned that an owner or operator could defeat the basic purpose of the unsaturated zone monitoring program by selecting a deep treatment zone. The purpose of the unsaturated zone monitoring program is to give relatively prompt feedback on the success of treatment in the treatment zone. If the treatment zone was deep, there would be a considerable lag time (possibly several years) between the time that waste was applied and the time that the failure of the treatment process was detected. EPA, therefore, concluded that there needed to be a maximum depth for the treatment zone.

Ultimately, EPA concluded that the treatment zone should be no deeper than 1.5 meters (5 feet).This depth from the initial surface soil elevation was chosen as a maximum depth for the treatment zone because soil conditions below this depth are generally not conducive to degradation and immobilization of hazardous constituents. Under the anaerobic and reducing conditions which occur in most soils below 1.5 meters, the solubility of most heavy metals increases. Also, the anaerobic conditions limit survival of the soil microflora necessary for degradation of most wastes. The 1.5 meter depth, as a maximum, should enable nearly all land treatment units the opportunity to operate successfully.

Today's regulations place one more constraint on the depth of the treatment zone. The Agency is today requiring a minimum distance of one meter (3 feet) between the bottom of the treatment zone and the seasonal high water table. This minimum distance is necessary to (1) allow for installation and implementation of the unsaturated zone monitoring, and (2) provide some minimum buffer to account for fluctuation in the seasonal high water table.

Unsaturated zone monitoring at land treatment units must include soil monitoring and soil pore-liquid monitoring immediately below the treatment zone. At least 15 cm (6 inches) of soil depth below the treatment zone is needed for adequate soil sampling. Thirty cm (12 inches) of soil will be sufficient, in most cases, for placement of the soil pore-liquid sampling device wholly below the treatment zone. However, due to the difficulties associated with field monitoring, sample collection will often occur somewhere above or below the desired depth. Hence, sufficient soil depth (above the seasonal high water table) must be available to account for the inherent errors associated with field monitoring. The Agency believes that a one meter soil depth will accomplish this.

The seasonal high water table, as specified in local soil surveys (which have often been conducted jointly by the Soil Conservation Service and the State Agricultural Extension Agency), will often fluctuate over time. The degree of fluctuation will vary depending on the hydrologic and geologic characteristics of a particular site. In most cases, the Agency believes that a one meter soil buffer will adequately account for this fluctuation.

3. *Treatment Demonstration (Section 264.272).* The first step in the establishment of a land treatment program is to conduct a treatment demonstration. The purpose of this step is to establish what combination of operating practices at the unit (given the natural constraints at the site such as soild characteristics and climate) can be used to completely degrade, transform or immobilize the hazardous constituents in the wastes that the owner or operator seeks to manage at the unit.

The treatment demonstration is used to define two elements of the land treatment program. First, it establishes what wastes may be managed at the unit. The owner or operator may only apply those hazardous wastes that he has shown can be degraded, transformed or immobilized such that hazardous constituents are not expected to emerge from the treatment zone. Second, the treatment demonstration will define the initial set of waste management practices (including waste application rates) that will be incorporated into the facility permit. These practices may be modified over time as data from the unsaturated zone monitoring program indicates the need for adjustments.

The treatment demonstration occurs before the unit is at full-scale operation under a permit. The information generated from the demonstration will be submitted to the Regional Administrator and will be used to set permit conditions.

The treatment demonstration presents issues that are analogous to those that EPA has addressed for trial burns in the hazardous waste incinerator regulations. A treatment demonstration may involve field testing of particular wastes on a sample soil plot, or it may involve laboratory testing. (These are not the only methods of making a treatment demonstration, as will be discussed later in this preamble.) Where field testing or laboratory analyses are used, hazardous waste disposal or treatment is occurring and RCRA provides that such an activity requires a permit. EPA has provided a limited mechanism under the permit regulations, in § 122.27, for the issuance of phased land treatment permits that will allow some owners and operators to make a treatment demonstration using field testing or laboratory analyses without first receiving a disposal or treatment permit separate from the actual facility permit.

The basic criterion used in evaluating a treatment demonstration is that it must be possible to achieve complete degradation, transformation or immobilization of the hazardous constituents in a waste if that waste is to be applied at the unit. Within the limits of the tests used in the demonstration, this is a standard that requires 100% treatment. EPA believes that land treatment should be limited to wastes for which complete treatment is possible; therefore, the "100% treatment" criterion is most appropriate. EPA recognizes that it will not always be possible to achieve 100% treatment at an operating unit because of variations in climatic and other conditions not fully under the control of the owner or operator. Thus, the failure to achieve 100% treatment at an operating unit does not necessarily constitute a permit violation but rather it will often be grounds for modifying permit conditions to maximize the success of treatment at the unit.

The treatment demonstration can be accomplished using information derived from published literature, laboratory studies, field studies or actual facility operating experience (i.e., monitoring results). Successful demonstrations will most often involve data obtained from several of the above sources.

A literature search on the particular waste in question should first be conducted. Information in the published literature may assist in the design of laboratory or field experiments, or significantly reduce or eliminate the need for additional experimentation. However, the Agency believes that, for most land treated hazardous wastes, an inadequate data base is available in the literature to predict unit-specific waste-soil interactions.

Laboratory studies may be used as rapid screening techniques for examining, within a reasonable time frame, the effects of various factors on treatment effectiveness. Extrapolation of this data to field conditions, however, may often be difficult because of the complex interactions occurring in the field. Therefore, field studies often will be necessary to verify certain lab-generated results.

For existing units, actual operating data (i.e., monitoring results) can also be effectively used to demonstrate treatment. The monitoring data must include results from soil-core, soil pore-liquid, and ground-water monitoring.

All data used to demonstrate the treatability of the hazardous constituents in a specific waste in a particular land treatment unit must be generated under conditions similar to those present at the unit. At a minimum, the following unit-specific characteristics and conditions must be simulated in the treatment demonstration:

(1) Characteristics of the land-treated waste;

(2) The depth and characteristics of the treatment zone;

(3) Topography of the treatment zone;

(4) Climate of the area; and

(5) Operating practices (such as waste application method and rate, tilling depth and frequency, and soil conditioning practices (*e.g.*, pH adjustment, fertilization, etc.)).

Specific guidance regarding the necessary elements of the treatment demonstration is provided in the *RCRA Land Treatment Guidance Document.*

4. *Design and Operating Requirements (Section 264.273).* In § 264.273, the regulations indicate what general design and operating requirements apply to land treatment units. The principal design and operating measures are those that are required as part of the land treatment program. These requirements can include limits on waste application rates and methods, measures to control soil pH, measures to enhance microbial or chemical reactions (*e.g.*, fertilization, tilling) and measures to control the moisture content of the treatment zone. The Regional Administrator will specify these design and operating conditions in the facility permit based on the results of the treatment demonstration under § 264.272.

In addition, there are other general design and operating requirements that apply to land treatment units that are analogous to those required at other types of land disposal units. The unit must have effective run-on and run-off management systems. These control systems are essential in limiting the transport of hazardous constituents either through the treatment zone toward ground water or off of the surface of the unit in an untreated condition where they may contaminate surface water or an off-site location.

Run-on controls are particularly important at land treatment units. EPA believes that proper treatment requires careful management of the soil's moisture content. Excess water in the treatment zone caused by run-on can significantly limit the treatment effectiveness and can also hinder such operations as tilling. In addition, run-on will increase the amount of water flowing down through the treatment zone and, therefore, increase the likelihood of the transport of hazardous constituents out of the treatment zone towards ground water.

Today's regulations provide that the owner or operator must design, construct, operate and maintain a run-on control system that is capable of preventing flow onto the active portion of the unit during the peak discharge from at least a 25-year storm. The peak discharge will have to be determined on a unit-specific basis and will depend on the rainfall patterns in the region as well as the size and terrain of the watershed. The rationale for the 25-year storm event is explained in the preamble discussion of the design and operating standards (Section VII.G.).

Today's rules also require that owners and operators of land treatment units must design, construct, maintain, and operate a run-off management system capable of collecting and controlling a water volume at least equivalent to a 24-hour, 25-year storm. The preamble discussion of the design and operating standards (Section VII.G.) contains further discussion of the rationale for this design.

Besides the general requirements to establish run-on and run-off systems, today's regulations require that the owner or operator manage the treatment zone in a manner designed to minimize run-off. In order for hazardous constituents to be properly treated, it is necessary that these constituents not be allowed to run off the surface of the unit. Minimization of run-off can be achieved through proper unit siting and design, particularly with regard to soil characteristics and slope, as well as through proper management of unit operation, including the method, rate, and scheduling of waste application.

Another requirement calls for control of wind dispersal at the unit if the treatment zone contains particulate matter that is subject to wind dispersal. Wind dispersal can be a serious concern at land treatment units because hazardous waste is generally placed on or barely under the soil surface. Measures to control wind dispersal will, however, be somewhat different than those used at other types of land disposal units. Potential control measures for land treatment units include establishment of vegetative cover, maintenance of proper surface soil moisture, and the use of chemical soil stabilizing agents.

5. *Food-chain Crops (Section 264.276).* In some cases an owner or operator may grow food-chain crops on a land treatment unit. This practice raises public health concerns. Accordingly, EPA has placed restrictions on the growth of food-chain crops on land treatment units. The Agency believes that food-chain crops can be safely grown on land treatment units if these standards are met.

Today's regulations on food-chain crops are basically the same as the restrictions found in the interim status standards. Growth of food-chain crops is not allowed unless the owner or operator complies with two primary criteria. First, he must demonstrate (for every hazardous constituent except cadmium) that hazardous constituents will not occur in greater concentrations in or on the crop grown on the unit than in or on the same crop grown on untreated soils under similar conditions in the same region. Second, if cadmium is a hazardous constituent at the unit, the owner or operator must comply with certain specified management practices that are designed to limit the entry of cadmium into the food chain.

The owner or operator must make the demonstration necessary to meet the first criterion before the crop is actually planted. This demonstration must describe the crop to be planted, the soil characteristics of the treatment zone (*e.g.*, pH, cation exchange capacity) and describe the procedures used in conducting any tests of crops, including the sample selection criteria, the sample size, the analytical methods and the statistical procedures used. Any tests attempting to measure crop uptake must be based on the specific wastes and application rates being used at the unit because these are critical factors in the validity of the test. The owner or operator may make this demonstration using field tests, greenhouse studies, available data, or, in the case or existing units, operating data. Of course, if the owner or operator wants to use field tests or greenhouse studies to make the demonstration, and he is not the owner or operator of an existing unit already growing the specific crop, he will have to obtain a permit for conducting such activities.

The analysis provided by the owner or operator must show that hazardous constituent levels in the crop grown at the unit will not exceed those found in the same crop grown on untreated soils under similar conditions in the same region. (This test does not, however, mean that the comparison crop would be from another hazardous waste land treatment unit; data from such units cannot be used as the basis for comparison.)

The basic philosophy of this requirement is similar to that used in Subpart F for ground-water protection. In the absence of specific standards for hazardous constituents in food, EPA believes it reasonable to assure that there will be no significant increase of such constituents in the human food chain as a result of hazardous waste disposal.

In defining the crop to be used for comparison purposes, EPA considered several options. These included (1) dropping the "in the same region" test or (2) revising the test to call for comparisons to a national average of hazardous constituents found in crops grown on untreated soils. EPA rejected the first option because it does not want to encourage owners and operators to "shop around" for comparison data from the region of the country where the crops contain the highest levels of certain metals or other constituents. This might allow more highly contaminated food-chain crops to be marketed from land treatment units.

The Agency rejected the second alternative because it believes that there is not yet an adequate national data base for most hazardous constituents in crops grown on untreated soils. Therefore, because the Agency has been unable to identify less burdensome but adequately protective demonstration alternatives, the alternatives in today's rules are the same as those in the interim status standards.

EPA has not provided for a health-based variance from the food-chain crop standard based on narrative criteria. EPA believes that specific contaminant limits for food should be established in national rulemaking to allow for input from Federal agencies like the Food and Drug Administration, which are chiefly responsible for setting such standards.

Today's regulations differ from the interim status standards in identifying the constituents of concern under the standard. The interim status standards require that the comparison must be made for constituents listed in Appendix VII and in Table I of § 261.24. Today's rules, however, require this same demonstration to be made for all hazardous constituents (i.e., all Appendix VIII constituents) that are reasonably expected to be in, or derived from, the waste being land treated.

The Agency has made this demonstration more comprehensive in light of several comments stating that the safety of food-chain crops grown on land treatment units could not be ensured if the required demonstration included only Appendix VII and Table I constituents. Commenters have observed that may hazardous constituents not listed in Appendix VII or Table 1 of § 261.24 could threaten human health if present in food-chain crops from land treatment units. The Agency agrees with these commenters and has decided, because of the high level of risk that could be associated with inadvertent or undetected non-compliance with the standards for food-chain crops, to require this more comprehensive demonstration.

If the owner or operator demonstrates that the food-chain crops grown at the unit will not have contaminant levels above those found in similar crops grown on untreated soils under similar circumstances in the same region, the Regional Administrator will indicate in the facility permit that these crops may be grown at the unit. The owner or operator may not plant any food-chain crop not identified in the permit.

The second component of the food-chain crop standard applies only to cadmium. The regulations set forth two sets of management practices that can be used to ensure that cadmium will not cause any adverse effects on human health or the environment. These requirements are nearly identical to those established in the Criteria for the Classification of Solid Waste Disposal Facilities and Practices (40 CFR Part 257). The rationale for the requirements are the same.

It should be noted that today's regulations provide for "phasing in" the limits on annual application rates according to the same schedule found in the Criteria. On February 5, 1981 EPA had proposed to eliminate this phasing-in approach from the Part 264 regulations. EPA has decided, however, to retain the phasing approach to maintain equity between solid and hazardous waste facility owners and operators. Since both standards address aggregate cadmium levels in the waste, hazardous wastes present no greater risks to food-chain crops than solid wastes if the standards are met.

6. *Unsaturated Zone Monitoring (Section 264.278).* As indicated earlier, the purpose of unsaturated zone monitoring is to provide feedback on the success of treatment in the treatment zone. The information obtained from this monitoring will be used to adjust the operating conditions at the unit in order to maximize degradation, transformation and immobilization of hazardous constituents in the treatment zone.

For example, if a significant increase of a hazardous constituent is detected in unsaturated zone monitoring, the owner or operator will examine more closely the facility characteristics that significantly affect the mobility and persistence of that constituent. These significant facility characteristics may include treatment zone characteristics (*e.g.*, pH, cation exchange capacity, organic matter content), or operational practices (*e.g.*, waste application method and rate). Modifications to one or more of these characteristics may be necessary to maximize treatment of the hazardous constituent within the treatment zone and to minimize additional migration of that constituent to below the treatment zone.

It should be emphasized that unsaturated zone monitoring is not a substitute for ground-water monitoring. Both are required at land treatment units. Ground-water monitoring is designed to determine the effect of hazardous waste leachate on the ground water. Unsaturated zone monitoring cannot perform that function as a general matter. Instead, unsaturated zone monitoring simply gives an indication of whether hazardous constituents are migrating out of the treatment zone.

Likewise, unsaturated zone monitoring is not equivalent to the leak detection monitoring that is used at some other types of disposal units (*e.g.*, double-lined surface impoundments). Leak detection monitoring is used in conjunction with a relatively "closed" design (*e.g.*, two liners with a drainage layer between them) that is designed to pick up any liquid migrating from the unit. EPA believes that such a design can be a substitute for the ground-water monitoring and response program of Subpart F.

Unsaturated zone monitoring, however, operates in an open system that allows liquids to pass through the unsaturated zone. While EPA believes that unsaturated zone monitoring is generally reliable, it cannot provide the same level of certainty about the migration of hazardous constituents from the facility that a double-lined surface impoundment (with a leak detection monitoring program) can provide. Therefore, unsaturated zone monitoring cannot be a substitute for ground-water monitoring.

Some commenters have expressed concern about the reliability and practicality of unsaturated zone monitoring, particularly soil-pore liquid monitoring. EPA believes that adequate technology and expertise is available to develop effective and reliable systems.

The Agency also believes that the inconvenience cited by some commenters can be avoided. Commenters stated that the placing of lysimeters (one type of device for monitoring soil-pore liquid) on the active portion of a land treatment unit would hinder site operations. However, the Agency knows of a number of existing land treatment units with monitoring systems engineered so that the above-ground portion of the device for sampling soil-pore liquid is located off the actual treatment zone. This and other methods can be used to avoid any inconvenience associated with the location of these devices.

The unsaturated zone monitoring program must be designed to determine the presence of hazardous constituents below the treatment zone. Generally this means that the owner or operator must monitor for the hazardous constituents identified for each hazardous waste that is placed in or on the treatment zone.

EPA believes, however, that there may be some situations where this general monitoring burden may be reduced without compromising the objectives of the unsaturated zone monitoring program. Some hazardous constituents will be more difficult to degrade, transform or immobilize than others. Therefore, if the owner or operator monitors for the constituents that are difficult to treat and can demonstrate that such constituents are not migrating from the treatment zone, then EPA can be reasonably certain that other hazardous constituents are being adequately treated.

The Regional Administrator may address this situation by selecting principal hazardous constituents (PHCs) for the unit. A PHC is a hazardous constituent contained in the waste applied at a unit that is difficult to degrade, transform or immobilize in the treatment zone. The owner or operator may ask the Regional Administrator to establish PHCs at the unit if the owner or operator can demonstrate to the Regional Administrator's satisfaction that degradation, transformation or immobilization of the PHCs will assure adequate treatment of the other hazardous constituents in the waste.

The Regional Administrator will be particularly concerned with two factors when deciding whether to establish PHCs. First, he will be concerned with the mobility of the constituent. Since PHCs will be monitored in the area below the treatment zone, the Regional Administrator will want to assure that the PHCs give an early warning of the failure of the treatment process. Therefore, a PHC must be one of the most mobile constituents in the treatment zone. Second, a PHC must be one of the most concentrated and persistent constituents in the treatment zone. This is to assure that the constituent provides a reliable indication of the success of treatment in the treatment zone.

In the selection of principal hazardous constituents, the Regional Administrator will evaluate the results of waste analyses, literature reviews, laboratory tests, and field studies. Waste analyses will be used to identify the hazardous constituents in the waste. Information obtained from literature reviews, laboratory tests, and field studies (including monitoring results for existing units) will be used to assess the relative mobility and persistence of the various hazardous constituents. The extent of data needed to support the selection of one or more principal hazardous constituents for a particular waste will be determined by the Regional Administrator.

Both soil-core and soil-pore liquid monitoring are required in today's rules. These two monitoring procedures are intended to complement one another. Soil-core monitoring will provide information primarily on the movement of "slower-moving" hazardous constituents (such as heavy metals), whereas soil-pore liquid monitoring will provide essential additional data on the movement of fast-moving, highly soluble hazardous constituents that soil-core monitoring may miss.

The general elements of the unsaturated zone monitoring program are patterned after those required for ground-water monitoring in Subpart F. As in the detection monitoring program, the unsaturated zone monitoring program is designed to determine whether the level of hazardous constituents in the soil or soil-pore liquid below the treament zone shows statistically significant increases over the background levels of those constituents in the soil or soil-pore liquid. In addition, today's regulations include requirements for monitoring systems, sampling frequency and sampling and analysis procedures and methods that are analogous to those in Subpart F. Some modifications of the Subpart F monitoring program must be made, however, to make it compatible with land treatment.

First, the basis for establishing background values differs. In the ground-water monitoring program, background values are based on data taken from upgradient monitoring wells. Such a concept is not applicable to land treatment units. Background values at land treatment units are established by sampling the soil and soil-pore liquid in a background plot. A background plot is generally a segment of the soil near the unit that has characteristics similar to that of the treatment zone and that has not been contaminated by hazardous waste. At a new unit, however, the owner or operator could use the actual treatment zone prior to waste application as the background plot. The key characteristic of the background plot is its similarity to the treatment zone.

Second, the unsaturated zone monitoring program will rely on statistical procedures that are somewhat different than those used for detection monitoring programs under Subpart F. In order to account for seasonal variations in soil-pore liquid quality, background values will be based on one year of quarterly sampling as in the detection monitoring program. Since background soil levels are not likely to change significantly during such a time frame, today's rules allow that background soil levels may be established following a one-time sampling. Unsaturated zone monitoring is similar to compliance monitoring, however, in that there may be several constituents to be monitored. Thus, the probability of an experiment error rate is high. Therefore, the statistical procedures used in the unsaturated zone monitoring program will be based on a narrative standard as used in the compliance monitoring program.

This standard seeks to provide "reasonable confidence" that the migration of hazardous constituents from the treatment zone will be indicated after balancing the risk of false positives and the risk of false negatives. (This preamble discusses the rationale for this standard in Section VII.D.10.) If the number of constituents to be monitored is small, then this standard can be met by the use of the Student's t-test protocol described in § 264.97(h).

While EPA believes that the standard for statistical procedures just described should be adequate for most situations, EPA intends to further analyze the appropriateness of other statistical procedures for unsaturated zone monitoring. For example, EPA is considering whether other factors that might affect background levels of soil pore-water quality should be specifically addressed in devising the monitoring protocols. EPA specifically asks for public comment on this issue.

Third, the unsaturated zone monitoring program does not call for measurements of the flow and direction of ground water. The gradient in the ground water is not relevant to unsaturated zone monitoring and, thus, such information is not necessary.

Fourth, the response to the detection of a statistically significant increase in Subpart M differs from the response required in Subpart F. The results of unsaturated zone monitoring are to be used in the modification of the operating practices at the unit. Thus, the required response is the submission, within 90 days, of a permit modification application that sets forth how the owner or operator will adjust his operating practices (including waste application rates) to maximize degradation, transformation and immobilization of hazardous constituents in the treatment zone. However, an opportunity exists in today's rules for not submitting the permit modification application, but only if the owner or operator can successfully demonstrate to the Regional Administrator that the statistically significant increase results from an error in sampling, analysis, or evaluation. This error demonstration must be submitted to the Regional Administrator within 90 days of the owner or operator's knowledge of the statistically significant increase.

As indicated earlier in this preamble, the appearance of hazardous constituents below the treatment zone does not in itself constitute a violation of the regulations. (This is analogous to the fact that a landfill liner which has been designed not to leak does not violate the design standards if the liner fails at some future time.) Under the regulatory strategy in these regulations, contaminants that are not controlled by the design and operating measures will be addressed by the monitoring and response program in Subpart F.

7. *Recordkeeping (Sections 264.279).* Today's rules state that the operating record for the unit (as required in § 264.73) must include information on the dates and rates of the application of hazardous wastes. Waste application dates and rates are two vital factors, as discussed earlier in this preamble, which the owner or operator must carefully track and manage in order to achieve proper waste treatment.

8. *Closure and Post-closure Care (Section 264.280).* The closure and post-closure care requirements in today's regulations are quite similar to those that are required in the interim status regulations. The interim status regulations, however, expressed the requirements as a set of considerations that were designed to achieve general environmental objectives stated in the regulations. Today's regulations state the general design and operating "considerations" as actual duties that the owner or operator must meet. Those duties are designed to achieve the same general environmental objectives as the interim status requirements.

During the closure period the owner or operator must continue the operating practices that are designed to maximize degradation, transformation, and immobilization at the unit. Operating practices designed to maximize treatment include tilling of the soil, control of soil pH and moisture content, and fertilization. These practices must generally be continued throughout the closure period. In addition, during the closure period, the owner or operator must continue those practices that were designed to minimize run-off from the treatment zone and to control wind dispersion (if needed). The run-on and run-off systems must be maintained. The owner or operator must also adhere to the restrictions on food-chain crops specified in the permit.

The owner or operator must continue to operate the unsaturated zone monitoring program as provided for under §264.278 with one exception. Soil-pore liquid monitoring may be terminated 90 days after the last application of waste at the unit. EPA expects that the fast-moving constituents that the soil-pore liquid monitoring system is designed to detect should migrate out of the treatment zone soon after these constituents are applied if they are to migrate at all. EPA believes that any such migration is likely to occur in less than 90 days after the waste is applied. After the 90 days, the soil-core monitoring program becomes the principal mechanism for detecting migration out of the treatment zone.

The major element of the closure procedures at a land treatment unit is the placement of a vegetative cover that is capable of maintaining growth without extensive maintenance. Section 264.280(a)(6) requires the owner or operator to establish a vegetative cover at such time that the cover will not substantially impede degradation, transformation, or immobilization of hazardous constituents. Thus, the vegetative cover must not be established until sufficient treatment has occurred so that the placement of the cover and termination of certain operating practices (e.g., tilling) will not substantially inhibit treatment processes.

Once the vegetative cover is established, certain general practices designed to maximize treatment processes (e.g., tilling) cannot be conducted without damaging or destroying the vegetative cover. Such practices should not, therefore, continue once the cover is established. Accordingly, today's regulations provide in § 264.280(a)(1) that those practices aimed at enhancing degradation, transformation, and immobilization of hazardous constituents that would be inconsistent with the establishment of the vegetative cover under § 264.280(a)(6) should not be continued once the cover is established.

A vegetative cover consists of any plant material established on the treatment zone to provide protection against wind or water erosion, or to aid in the treatment of hazardous constituents. The major function of the vegetative cover during closure and post-closure care is to minimize wind and water erosion. Perennial grasses are often used because they can be rapidly established into a thorough cover. However, the best suited plant species will depend on the season and region of the country. Agronomists from the State Agricultural Extension Service, USDA, or nearby universities can be valuable sources of information regarding crop selection and cultivation practices which are best suited to a given region.

Section 246.115 of the general requirements for closure requires that the owner or operator submit a certification from an independent registered professional engineer that a unit has been closed in accordance with the approved closure plan specified in the permit. In the case of land treatment units, EPA believes that a qualified soil scientist should be as qualified as a professional engineer to evaluate the adequacy of such measures as vegetative cover. Therefore, today's regulations provide that an independent qualified soil scientist may make the certification.

During the post-closure care period, the owner or operator must continue many of the activities required during the active life (including the closure period). These include control of wind dispersal, maintenance of run-on and run-off systems and continuance of food-chain crop restrictions. The owner or operator must also continue soil-core monitoring but may suspend soil-pore liquid monitoring 90 days after the date of the last waste application. (This time period may have already passed during the closure period.) In addition, the vegetative cover established during closure must be maintained.

The owner or operator must also continue to take actions that foster degradation, transformation and immobilization processes in the treatment zone. These operating measures must be tempered somewhat during the post-closure care period. Only those measures that do not interfere with the other post-closure care requirements should be continued. Thus, the application of lime to maintain the pH in the treatment zone is an acceptable practice but tilling of the soil that destroys the vegetative cover at the unit should not be continued. The Regional Administrator may wish to state in the facility permit, the level of treatment, particularly degradation or transformation, required at a particular site prior to the start of post-closure care. This would greatly influence the type and extent of actual "treatment" activities necessary during the post-closure care period and may assure greater control over completion of these treatment processes. Guidance for specification of levels of treatment is provided in the *RCRA Land Treatment Guidance Document.* (See Section VII.G. of this Preamble.)

The post-closure care regulations also set out a variance that would allow the owner or operator to be relieved from compliance with the post-closure care requirements as well as the closure requirement for establishment of a vegetative cover. This variance can be obtained if the Regional Administrator finds, based on a demonstration by the owner or operator that the level of hazardous constituents *within* the treatment zone does not exceed the background values for those constituents by statistically significant amounts. Such a demonstration may be made at any time after the last application of waste is made at the unit. The sampling and data evaluation standards, including the requirements for evaluation of statistical significance, are specified in today's rules. These requirements are almost identical to corresponding standards contained in § 264.278. They include only soil monitoring and analysis, however, not soil-pore liquid monitoring.

It is important to note that an owner or operator who can successfully make the showing that hazardous constituents are no longer present in the treatment zone at statistically significant amounts may be eligible for a further exemption during the post-closure care period. If the owner or operator can also demonstrate that no hazardous constituents have migrated below the treatment zone during the active life of the land treatment unit, there is little prospect that corrective action measures under Subpart F would be necessary. Accordingly, the regulations provide that an owner or operator that can make both such demonstrations to the Regional Administrator may be exempted from Subpart F.

9. *Special Requirements for Ignitable or Reactive Waste (Section 264.281).* As is required for the other types of land disposal units, today's regulations restrict land treatment of ignitable and reactive waste. The rationale for this provision is the same for land treatment as it is for the other types of disposal units.

10. *Special Requirements for Incompatible Wastes (Section 264.282).* As is required for other types of land disposal units, today's regulations restrict land treatment of incompatible waste. The rationale for this provision is the same for land treatment as it is for the other types of disposal units. It should be recognized, however, that one way a waste is incompatible with a land treatment unit occurs when it operates to undermine treatment processes in the treatment zone (*e.g.,* by destroying microbial populations).

Subpart M—Land Treatment

§ 264.270 Applicability.

The regulations in this subpart apply to owners and operators of facilities that treat or dispose of hazardous waste in land treatment units, except as § 264.1 provides otherwise.

§ 264.271 Treatment program.

(a) An owner or operator subject to this subpart must establish a land treatment program that is designed to ensure that hazardous constituents placed in or on the treatment zone are degraded, transformed, or immobilized within the treatment zone. The Regional Administrator will specify in the facility permit the elements of the treatment program, including:

(1) The wastes that are capable of being treated at the unit based on a demonstration under § 264.272;

(2) Design measures and operating practices necessary to maximize the success of degradation, transformation, and immobilization processes in the treatment zone in accordance with § 264.273(a); and

(3) Unsaturated zone monitoring provisions meeting the requirements of § 264.278.

(b) The Regional Administrator will specify in the facility permit the hazardous constituents that must be degraded, transformed, or immobilized under this subpart. Hazardous constituents are constituents identified in Appendix VIII of Part 261 of this chapter that are reasonably expected to be in, or derived from, waste placed in or on the treatment zone.

(c) The Regional Administrator will specify the vertical and horizontal dimensions of the treatment zone in the facility permit. The treatment zone is the portion of the unsaturated zone below and including the land surface in which the owner or operator intends to maintain the conditions necessary for effective degradation, transformation, or immobilization of hazardous constituents. The maximum depth of the treatment zone must be:

(1) No more than 1.5 meters (5 feet) from the initial soil surface; and

(2) More than 1 meter (3 feet) above the seasonal high water table.

§ 264.272 Treatment demonstration.

(a) For each waste that will be applied to the treatment zone, the owner or operator must demonstrate, prior to application of the waste, that hazardous constituents in the waste can be completely degraded, transformed, or immobilized in the treatment zone.

(b) In making this demonstration, the owner or operator may use field tests, laboratory analyses, available data, or, in the case of existing units, operating data. If the owner or operator intends to conduct field tests or laboratory analyses in order to make the demonstration required under paragraph (a) of this section, he must obtain a treatment or disposal permit under § 122.27(c). The Regional Administrator will specify in this permit the testing, analytical, design, and operating requirements (including the duration of the tests and analyses, and, in the case of field tests, the horizontal and vertical dimensions of the treatment zone, monitoring procedures, closure and clean-up activities) necessary to meet the requirements in paragraph (c) of this section.

(c) Any field test or laboratory analysis conducted in order to make a demonstration under paragraph (a) of this section must:

(1) Accurately simulate the characteristics and operating conditions for the proposed land treatment unit including:

(i) The characteristics of the waste (including the presence of Appendix VIII of Part 261 of this chapter constituents);

(ii) The climate in the area;

(iii) The topography of the surrounding area;

(iv) The characteristics of the soil in the treatment zone (including depth); and

(v) The operating practices to be used at the unit.

(2) Be likely to show that hazardous constituents in the waste to be tested will be completely degraded,

transformed, or immobilized in the treatment zone of the proposed land treatment unit; and

(3) Be conducted in a manner that protects human health and the environment considering:

(i) The characteristics of the waste to be tested;

(ii) The operating and monitoring measures taken during the course of the test;

(iii) The duration of the test;

(iv) The volume of waste used in the test;

(v) In the case of field tests, the potential for migration of hazardous constituents to ground water or surface water.

§ 264.273 Design and operating requirements.

The Regional Administrator will specify in the facility permit how the owner or operator will design, construct, operate, and maintain the land treatment unit in compliance with this section.

(a) The owner or operator must design, construct, operate, and maintain the unit to maximize the degradation, transformation, and immobilization of hazardous constituents in the treatment zone. The owner or operator must design, construct, operate, and maintain the unit in accord with all design and operating conditions that were used in the treatment demonstration under § 264.272. At a minimum, the Regional Administrator will specify the following in the facility permit:

(1) The rate and method of waste application to the treatment zone;

(2) Measures to control soil pH;

(3) Measures to enhance microbial or chemical reactions (*e.g.*, fertilization, tilling); and

(4) Measures to control the moisture content of the treatment zone.

(b) The owner or operator must design, construct, operate, and maintain the treatment zone to minimize run-off of hazardous constituents during the active life of the land treatment unit.

(c) The owner or operator must design, construct, operate, and maintain a run-on control system capable of preventing flow onto the treatment zone during peak discharge from at least a 25-year storm.

(d) The owner or operator must design, construct, operate, and maintain a run-off management system to collect and control at least the water volume resulting from a 24-hour, 25-year storm.

(e) Collection and holding facilities (*e.g.*, tanks or basins) associated with run-on and run-off control systems must be emptied or otherwise managed expeditiously after storms to maintain the design capacity of the system.

(f) If the treatment zone contains particulate matter which may be subject to wind dispersal, the owner or operator must manage the unit to control wind dispersal.

(g) The owner or operator must inspect the unit weekly and after storms to detect evidence of:

(1) Deterioration, malfunctions, or improper operation of run-on and run-off control systems; and

(2) Improper functioning of wind dispersal control measures.

§§ 264.274–264.275 [Reserved]

§ 264.276 Food-chain crops.

The Regional Administrator may allow the growth of food-chain crops in or on the treatment zone only if the owner or operator satisfies the conditions of this section. The Regional Administrator will specify in the facility permit the specific food-chain crops which may be grown.

(a)(1) The owner or operator must demonstrate that there is no substantial risk to human health caused by the growth of such crops in or on the treatment zone by demonstrating, prior to the planting of such crops, that hazardous constituents other than cadmium:

(i) Will not be transferred to the food or feed portions of the crop by plant uptake or direct contact, and will not otherwise be ingested by food-chain animals (*e.g.*, by grazing); or

(ii) Will not occur in greater concentrations in or on the food or feed portions of crops grown on the treatment zone than in or on identical portions of the same crops grown on untreated soils under similar conditions in the same region.

(2) The owner or operator must make the demonstration required under this paragraph prior to the planting of crops at the facility for all constituents identified in Appendix VIII of Part 261 of this chapter that are reasonably expected to be in, or derived from, waste placed in or on the treatment zone.

(3) In making a demonstration under this paragraph, the owner or operator may use field tests, greenhouse studies, available data, or, in the case of existing units, operating data, and must:

(i) Base the demonstration on conditions similar to those present in the treatment zone, including soil characteristics (*e.g.*, pH, cation exchange capacity), specific wastes, application rates, application methods, and crops to be grown; and

(ii) Describe the procedures used in conducting any tests, including the sample selection criteria, sample size, analytical methods, and statistical procedures.

(4) If the owner or operator intends to conduct field tests or greenhouse studies in order to make the demonstration required under this paragraph, he must obtain a permit for conducting such activities.

(b) The owner or operator must comply with the following conditions if cadmium is contained in wastes applied to the treatment zone:

(1)(i) The pH of the waste and soil mixture must be 6.5 or greater at the time of each waste application, except for waste containing cadmium at concentrations of 2 mg/kg (dry weight) or less;

(ii) The annual application of cadmium from waste must not exceed 0.5 kilograms per hectare (kg/ha) on land used for production of tobacco, leafy vegetables, or root crops grown for human consumption. For other food-chain crops, the annual cadmium application rate must not exceed:

Time period	Annual Cd application rate (kilograms per hectare)
Present to June 30, 1984	2.0
July 1, 1984 to Dec. 31, 1986	1.25
Beginning Jan. 1, 1987	0.5

(iii) The cumulative application of cadmium from waste must not exceed 5 kg/ha if the waste and soil mixture has a pH of less than 6.5; and

(iv) If the waste and soil mixture has a pH of 6.5 or greater or is maintained at a pH of 6.5 or greater during crop growth, the cumulative application of cadmium from waste must not exceed: 5 kg/ha if soil cation exchange capacity (CEC) is less than 5 meq/100g; 10 kg/ha if soil CEC is 5–15 meq/100g; and 20 kg/ha if soil CEC is greater than 15 meq/100g; or

(2)(i) Animal feed must be the only food-chain crop produced;

(ii) The pH of the waste and soil mixture must be 6.5 or greater at the time of waste application or at the time the crop is planted, whichever occurs later, and this pH level must be maintained whenever food-chain crops are grown;

(iii) There must be an operating plan which demonstrates how the animal feed will be distributed to preclude ingestion by humans. The operating plan must describe the measures to be taken to safeguard against possible health hazards from cadmium entering the food chain, which may result from alternative land uses; and

(iv) Future property owners must be notified by a stipulation in the land record or property deed which states that the property has received waste at high cadmium application rates and that food-chain crops must not be grown except in compliance with paragraph (b)(2) of this section.

§ 264.277 [Reserved]

§ 264.278 Unsaturated zone monitoring.

An owner or operator subject to this subpart must establish an unsaturated zone monitoring program to discharge the following responsibilities:

(a) The owner or operator must monitor the soil and soil-pore liquid to determine whether hazardous constituents migrate out of the treatment zone.

(1) The Regional Administrator will specify the hazardous constituents to be monitored in the facility permit. The hazardous constituents to be monitored are those specified under § 264.271(b).

(2) The Regional Administrator may require monitoring for principal hazardous constituents (PHCs) in lieu of the constituents specified under § 264.271(b). PHCs are hazardous constituents contained in the wastes to be applied at the unit that are the most difficult to treat, considering the combined effects of degradation, transformation, and immobilization. The Regional Administrator will establish PHCs if he finds, based on waste analyses, treatment demonstrations, or other data, that effective degradation, transformation, or immobilization of the PHCs will assure treatment at at least equivalent levels for the other hazardous constituents in the wastes.

(b) The owner or operator must install an unsaturated zone monitoring system that includes soil monitoring using soil cores and soil-pore liquid monitoring using devices such as lysimeters. The unsaturated zone monitoring system must consist of a sufficient number of sampling points at appropriate locations and depths to yield samples that:

(1) Represent the quality of background soil-pore liquid quality and the chemical make-up of soil that has not been affected by leakage from the treatment zone; and

(2) Indicate the quality of soil-pore liquid and the chemical make-up of the soil below the treatment zone.

(c) The owner or operator must establish a background value for each hazardous constituent to be monitored under paragraph (a) of this section. The permit will specify the background values for each constituent or specify the procedures to be used to calculate the background values.

(1) Background soil values may be based on a one-time sampling at a background plot having characteristics similar to those of the treatment zone.

(2) Background soil-pore liquid values must be based on at least quarterly sampling for one year at a background plot having characteristics similar to those of the treatment zone.

(3) The owner or operator must express all background values in a form necessary for the determination of statistically significant increases under paragraph (f) of this section.

(4) In taking samples used in the determination of all background values, the owner or operator must use an unsaturated zone monitoring system that complies with paragraph (b)(1) of this section.

(d) The owner or operator must conduct soil monitoring and soil-pore liquid monitoring immediately below the treatment zone. The Regional Administrator will specify the frequency and timing of soil and soil-pore liquid monitoring in the facility permit after considering the frequency, timing, and rate of waste application, and the soil permeability. The owner or operator must express the results of soil and soil-pore liquid monitoring in a form necessary for the determination of statistically significant increases under paragraph (f) of this section.

(e) The owner or operator must use consistent sampling and analysis procedures that are designed to ensure sampling results that provide a reliable indication of soil-pore liquid quality and the chemical make-up of the soil below the treatment zone. At a minimum, the owner or operator must implement procedures and techniques for:

(1) Sample collection;

(2) Sample preservation and shipment;

(3) Analytical procedures; and

(4) Chain of custody control.

(f) The owner or operator must determine whether there is a statistically significant change over background values for any hazardous constituent to be monitored under paragraph (a) of this section below the treatment zone each time he conducts soil monitoring and soil-pore liquid monitoring under paragraph (d) of this section.

(1) In determining whether a statistically significant increase has occurred, the owner or operator must compare the value of each constituent, as determined under paragraph (d) of this section, to the background value for that constituent according to the statistical procedure specified in the facility permit under this paragraph.

(2) The owner or operator must determine whether there has been a statistically significant increase below the treatment zone within a reasonable time period after completion of sampling. The Regional Administrator will specify that time period in the facility permit after considering the complexity of the statistical test and the availability of laboratory facilities to perform the analysis of soil and soil-pore liquid samples.

(3) The owner or operator must determine whether there is a statistically significant increase below the treatment zone using a statistical procedure that provides reasonable confidence that migration from the treatment zone will be identified. The Regional Administrator will specify a statistical procedure in the facility permit that he finds:

(i) Is appropriate for the distribution of the data used to establish background values; and

(ii) Provides a reasonable balance between the probability of falsely identifying migration from the treatment zone and the probability of failing to identify real migration from the treatment zone.

(g) If the owner or operator determines, pursuant to paragraph (f) of this section, that there is a statistically significant increase of hazardous constituents below the treatment zone, he must:

(1) Notify the Regional Administrator of this finding in writing within seven days. The notification must indicate what constituents have shown statistically significant increases.

(2) Within 90 days, submit to the Regional Administrator an application for a permit modification to modify the operating practices at the facility in order to maximize the success of degradation, transformation, or immobilization processes in the treatment zone.

(h) If the owner or operator determines, pursuant to paragraph (f) of this section, that there is a statistically significant increase of hazardous constituents below the treatment zone, he may demonstrate that a source other than regulated units caused the increase or that the increase resulted from an error in sampling, analysis, or evaluation. While the owner or operator may make a demonstration under this paragraph in addition to, or in lieu of, submitting a permit modification application under paragraph (g)(2) of this section, he is not relieved of the requirement to submit a permit modification application within the time specified in paragraph (g)(2) of this section unless the demonstration made under this paragraph successfully shows that a source other than regulated units caused the increase or that the increase resulted from an error in sampling, analysis, or evaluation. In making a demonstration under this paragraph, the owner or operator must:

(1) Notify the Regional Administrator in writing within seven days of determining a statistically significant increase below the treatment zone that he intends to make a determination under this paragraph;

(2) Within 90 days, submit a report to the Regional Administrator demonstrating that a source other than the regulated units caused the increase or that the increase resulted from error in sampling, analysis, or evaluation;

(3) Within 90 days, submit to the Regional Administrator an application for a permit modification to make any appropriate changes to the unsaturated zone monitoring program at the facility; and

(4) Continue to monitor in accordance with the unsaturated zone monitoring program established under this section.

§ 264.279 Recordkeeping.

The owner or operator must include hazardous waste application dates and rates in the operating record required under § 264.73.

§ 264.280 Closure and post-closure care.

(a) During the closure period the owner or operator must:

(1) Continue all operations (including pH control) necessary to maximize degradation, transformation, or immobilization of hazardous constituents within the treatment zone as required under § 264.273(a), except to the extent such measures are inconsistent with paragraph (a)(8) of this section.

(2) Continue all operations in the treatment zone to minimize run-off of hazardous constituents as required under § 264.273(b);

(3) Maintain the run-on control system required under § 264.273(c);

(4) Maintain the run-off management system required under § 264.273(d);

(5) Control wind dispersal of hazardous waste if required under § 264.273(f);

(6) Continue to comply with any prohibitions or conditions concerning growth of food-chain crops under § 264.276;

(7) Continue unsaturated zone monitoring in compliance with § 264.278, except that soil-pore liquid monitoring may be terminated 90 days after the last application of waste to the treatment zone; and

(8) Establish a vegetative cover on the portion of the facility being closed at such time that the cover will not substantially impede degradation, transformation, or immobilization of hazardous constituents in the treatment zone. The vegetative cover must be capable of maintaining growth without extensive maintenance.

(b) For the purpose of complying with § 264.115, when closure is completed the owner or operator may submit to the Regional Administrator certification by an independent qualified soil scientist, in lieu of an independent registered professional engineer, that the facility has been closed in accordance with the specifications in the approved closure plan.

(c) During the post-closure care period the owner or operator must:

(1) Continue all operations (including pH control) necessary to enhance degradation and transformation and sustain immobilization of hazardous constituents in the treatment zone to the extent that such measures are consistent with other post-closure care activities;

(2) Maintain a vegetative cover over closed portions of the facility;

(3) Maintain the run-on control system required under § 264.273(c);

(4) Maintain the run-off management system required under § 264.273(d);

(5) Control wind dispersal of hazardous waste if required under § 264.273(f);

(6) Continue to comply with any prohibitions or conditions concerning growth of food-chain crops under § 264.276; and

(7) Continue unsaturated zone monitoring in compliance with § 264.278, expect that soil-pore liquid monitoring may be terminated 90 days after the last application of waste to the treatment zone.

(d) The owner or operator is not subject to regulation under paragraphs (a)(8) and (c) of this section if the Regional Administrator finds that the level of hazardous constituents in the treatment zone soil does not exceed the background value of those constituents by an amount that is statistically significant when using the test specified in paragraph (d)(3) of this section. The owner or operator may submit such a demonstration to the Regional Administrator at any time during the closure of post-closure care periods. For the purposes of this paragraph:

(1) The owner or operator must establish background soil values and determine whether there is a statistically significant increase over those values for all hazardous constituents specified in the facility permit under § 264.271 (b).

(i) Background soil values may be based on a one-time sampling of a background plot having characteristics similar to those of the treatment zone.

(ii) The owner or operator must express background values and values for hazardous constituents in the treatment zone in a form necessary for the determination of statistically significant increases under paragraph (d)(3) of this section.

(2) In taking samples used in the determination of background and treatment zone values, the owner or operator must take samples at a sufficient number of sampling points and at appropriate locations and depths to yield samples that represent the chemical make-up of soil that has not been affected by leakage from the treatment zone and the soil within the treatment zone, respectively.

(3) In determining whether a statistically significant increase has occurred, the owner or operator must compare the value of each constituent in the treatment zone to the background value for that constituent using a statistical procedure that provides reasonable confidence that constituent presence in the treatment zone will be identified. The owner or operator must use a statistical procedure that:

(i) Is appropriate for the distribution of the data used to establish background values; and

(ii) Provides a reasonable balance between the probability of falsely identifying hazardous constituent presence in the treatment zone and the probability of failing to identify real presence in the treatment zone.

(e) The owner or operator is not subject to regulation under Subpart F of this chapter if the Regional Administrator finds that the owner or operator satisfies paragraph (d) of this section and if unsaturated zone monitoring under § 264.278 indicates that hazardous constituents have not migrated beyond the treatment zone during the active life of the land treatment unit.

§ 264.281 Special requirements for ignitable or reactive waste.

The owner or operator must not apply ignitable or reactive waste to the treatment zone unless:

(a) The waste is immediately incorporated into the soil so that:

(1) The resulting waste, mixture, or dissolution of material no longer meets the definition of ignitable or reactive

waste under §§ 261.21 or 261.23 of this chapter; and

(2) Section 264.17(b) is complied with; or

(b) The waste is managed in such a way that it is protected from any material or conditions which may cause it to ignite or react.

§ 264.282 Special requirements for incompatible wastes.

The owner or operator must not place incompatible wastes, or incompatible wastes and materials (see Appendix V of this part for examples), in or on the same treatment zone, unless § 264.17(b) is complied with.

§§ 264.283–264.299 [Reserved]

10.7 RCRA PART 264 HAZARDOUS WASTE REGULATIONS REGULATIONS PREAMBLE (EXCERPT)

E. Design and Operating Standards: General Discussion (Part 264, Subparts K,L,M,N)

1. *Introduction.* The Part 264 regulations promulgated today for surface impoundments, piles, landfills, and land treatment units used to treat, store, or dispose of hazardous wastes include a set of design and operating standards in Subparts K–N in addition to the ground-water protection requirements in Subpart F. The design and operating standards are of two types. First is a set of standards that are analogous and, in some cases, identical to the interim statutes standards that have already been established for these units in 40 CFR Part 265. These standards generally require sound operating practices. Second is a set of new and generally more rigorous standards that emphasize environmentally protective design and construction features as well as complementary operating and maintenance practices. This preamble discussion will focus on the latter set of standards.

In developing the design and operating standards, EPA has considered all of its previous rulemaking activities (see the discussion in section II of this preamble) and the public comments received as part of the rulemaking process. While the comments submitted to EPA were by no means uniform, the following general guidelines appear to reflect a broad consensus and, in EPA's opinion, a sound approach to writing the design and operating standards (as well as the Subpart F ground-water standards).

(1) The standards should reflect clearly articulated regulatory goals.

(2) The standards should be understandable by the regulated community and the general public and capable of being administered efficiently by permit-issuing authorities.

(3) The standards should require different units to achieve consistent environmental results, while providing ample flexibility for site-specific factors to be considered during the permitting process.

(4) The standards should be specific enough to provide as much certainty as possible, but, again, should be flexible enough to allow environmental results to be achieved in the manner that is most cost-effective for a specific combination of wastes, unit, and location and that does not stifle innovation.

Accordingly, the major feature of the Subparts K–N regulations promulgated today is a set of design performance standards. The standards clearly set forth the environmental results to be achieved (e.g., there must be no migration of wastes from a landfill during its active life) in terms of generalized design requirements (e.g., a landfill must have a liner to prevent the migration of wastes from the landfill during its active life).

The design performance requirement sets forth general performance goals (e.g., a liner must have appropriate chemical properties and sufficient strength and thickness to prevent failure). However, EPA recognizes that there are many ways to achieve such goals. Therefore, detailed specifications are not set forth in these rules but, rather, are left to be determined during the permitting process. EPA has developed in the past and will continue to develop technical manuals and guidance documents to assist permit applicants and permitting authorities in evaluating the appropriateness of various equipment, materials, and designs in the context of specific units, wastes and locations (see the discussion in Section VII. E.8. below.)

The design and operating standards generally apply to all surface impoundments, waste piles, land treatment units, and landfills, including both new and existing units. However, portions of units on which wastes have been placed prior to permit issuance are exempt from certain design requirements which would require burdensome and possibly hazardous retrofitting of the units. (See Section VII E.6. below.) Furthermore, the regulations provide a waiver from some design and operating standards if the permit applicant demonstrates that there will never be any ground water or surface water contamination if the waiver is granted.

2. *Major Features of the Design and Operating Standards.* The regulatory goal adopted in the design and operating standards is to minimize the formation and migration of leachate to the adjacent subsurface soil or ground water or surface water. Thus, while the ground water protection requirements are intended to result in detection, evaluation and, if necessary, correction of ground water contamination, the design and operating standards are intended to minimize the possibility of such contamination. Thus, these two sets of standards are complementary. One set is preventive; the other offers a cure for situations in which the preventive measures have not sufficed to eliminate threats to human health and the environment.

The regulatory goal of minimizing the formation and migration of leachate is achieved differently with respect to different units. For land treatment units, the design and operating standards require that hazardous constituents be degraded, transformed, or immobilized within the treatment zone. Due to the unique features of land treatment units, these units are discussed separately below in Section VII.H. of this preamble.

For surface impoundments, piles, and landfills, any treatment that occurs is usually not instantaneous and is often incomplete. (An exception is neutralization surface impoundments in which treatment may be very quick and complete. See the discussion above in Section IV.B.2. of this preamble.) Therefore, EPA has assumed in writing the standards that some hazardous constituents will be capable of migrating from these units to adjacent subsurface soil or ground water or surface water. For these units, therefore, EPA has developed regulations to minimize the rate and volume of waste and leachate migration. The regulations have the following key features:

(1) Each impoundment, pile, or landfill (except existing portions) must have a liner that is designed and installed to prevent any migration of wastes out of the unit to the adjacent subsurface soil or ground water or surface water throughout the active life of the unit.

(2) To minimize the potential for release of hazardous constituents both during the unit's active life and after the unit is closed:

a. Piles and landfills must have leachate collection and removal systems (during their active lives and, after closure, until leacate is no longer detected), as well as measures to prevent run-on of liquids into the unit.

b. Surface impoundments must have all wastes and waste residues either removed or solidified at closure. Piles must have all wastes and waste residues removed at closure.

(3) To further minimize post-closure leaching of hazardous constituents, any unit in which hazardous constituents are not entirely removed or decontaminated at closure must have a final cover (cap) placed on top to minimize the percolation of liquids into the unit. The cap must be maintained until the end of the post-closure period.

3. *Rationale Underlying the Design and Operating Standards.* In developing standards for land disposal units, EPA considered and rejected the option of promulgating ground water standards in conjunction with only those operating requirements already in the Part 265 interim status standards. EPA expects that today's Part 264 ground water protection standards in Subpart F will, in most cases, adequately protect human health and the environment from ground water contamination. They also address surface water contamination threats to some degree, since land disposal units that contaminate surface water often do so by leaching waste constituents to ground water, which then serves as a conduit to adjacent surface water. However, EPA concludes that sound policy as well as the law support an approach that supplements those standards, where appropriate, with design and operating standards that minimize contamination threats by controlling the source of contamination, i.e., the unit itself.

First, at present, the technologies for detecting and remedying ground-water contamination, while fairly advanced, remain subject to error. To detect ground-water contamination, one must carefully study the hydrogeologic setting to properly place monitoring wells. Because each setting is unique and often is heterogeneous, occasional errors in well placement are inevitable despite the best efforts of owners and operators to comply with Subpart F. Furthermore, the technology of performing corrective action is new. The Agency's and the regulated community's experience in conducting remediation activities (beyond the feasibility study stage) is fairly limited to date. Thus, while ground-water monitoring and remediation techniques are important activities and thus are appropriately required in Subpart F, design and operating standards will significantly increase confidence by reducing the potential for ground-water contamination.

Second, corrective action can be expensive. It may involve pumping and treating large volumes of contaminated ground water for many years. In some cases, the owner or operator may lack the financial resources to perform the required corrective action. Elsewhere in this preamble (Section IV.B.1.) EPA discusses and invites public comment on options for financial responsibility requirements to address this problem. Any such requirements that might be promulgated are likely to reduce, but cannot eliminate entirely, the possibility that owners or operators of land disposal units will lack the finances needed to perform necessary corrective action. Furthermore, if ground-water contamination occurs after the owner or operator has completed all required post-closure maintenance and monitoring activities required in his permit, substantial sums of money may need to be drawn from the Fund established in CERCLA or otherwise expended by the public. Design and operating practices can reduce this problem by minimizing the amount and rate of leachate migration to the subsurface soil and ground water.

For the above reasons, EPA believes that design and operating standards are necessary to protect human health and the environment. EPA emphasizes, however, that despite the promulgation of design and operating standards, the Subpart F standards are also necessary to fully protect human health and the environment. Design and operating features, like the ground-water monitoring and response program, are effective but not fail-safe. Most land disposal units, however well designed, will eventually leak after closure to some extent. Furthermore, many existing units lack adequate liners and may already be leaking. When leaking occurs, EPA expects that compliance with the Subpart F requirements will, in most cases, result in detection of contamination that may threaten human health and the environment and in remediation of the threats. In addition, EPA anticipates that the technologies needed to implement Subpart F will continue to advance, just as they have rapidly improved in recent years. Thus, the standards promulgated today provide a two-part "prevention and cure" system, each part adding to confidence in the system as a whole.

This combined approach, including both design and operating standards and monitoring and corrective action requirements, comports with the language and intent of Section 3004 of RCRA. This Section requires EPA to promulgate regulations establishing such performance standards as may be necessary to protect human health and the environment, and direct that these standards include requirements respecting:

(1) Operating methods, techniques and practices as may be satisfactory to the EPA Administrator;

(2) Reporting, monitoring, and inspection;

(3) Location, design, and construction of facilities; and

(4) Contingency plans for effective action to minimize unanticipated damage from hazardous waste treatment, storage, or disposal.

EPA believes that the two-pronged approach promulgated today successfully addresses the various factors listed by Section 3004. We further believe that the regulatory approach will help a concerned public gain confidence that land disposal units permitted pursuant to the standards promulgated today will protect human health and the environment.

4. *Rationale for Requiring Liners that Prevent Migration of Wastes During the Active Life of the Unit.*

During our development of the requirement that each impoundment, pile, and landfill have a liner designed to "prevent" migration of wastes out of the unit during the active life of the unit, EPA considered requiring instead that the liner merely "minimize" migration. This distinction has significant practical consequences with respect to the types of materials that may be used for liners. For example, while a clay liner minimizes migrations, it does not completely prevent migration, since liquids will slowly enter the pores of the clay, move through it, and ultimately flow out of it.

EPA decided to require a design to prevent migration during the unit's active life. This standard, together with requirements to minimize post-closure migration, represent the best available technology to achieve the goal of minimizing the rate and volume of leachate migration for all time. Merely designing to minimize migration during the unit's active life would result in an increased risk of ground-water contamination both during the unit's active life and after closure.

When a synthetic membrane liner, for example, is installed in a landfill, the leachate collection and removal system installed above the liner (as required by today's regulations for landfills and piles) can achieve virtually a 100% removal efficiency. In contrast, if a clay liner is used, some leachate will seep into the liner rather than be removed through the drainage layer. This leachate will remain in the soil after closure and will likely migrate to the ground water at some future time.

Prevention, rather than minimization, of leachate migration similarly produces better environmental results in the case of surface impoundments used to dispose of hazardous wastes. As discussed in Section VII.F. of this preamble, an impoundment is not required to have a leachate collection system, and thus no leachate is removed during its active life. One of the regulatory options for closing a surface impoundment is to solidify remaining wastes and cover the impoundment with a low permeability cap (i.e., to close the unit in the same manner as a landfill). These measures will likely nearly eliminate further migration of hazardous constituents from the impoundment for the near term and will minimize migration into the distant future. If the liner has prevented migration throughout the active life of the impoundment, then all wastes and leachate will still be above the liner at closure where they can be dealt with relatively easily. But if the leachate has migrated into a soil-based (e.g., clay) liner prior to closure, future migration of these wastes is more likely. A liner that prevents rather than minimizes leachate migration provides added assurance that environmental contamination will not occur.

The above rationale does not apply fully to a pile or to a surface impoundment from which all wastes and waste residues will be removed at closure (i.e., "storage" piles or surface impoundments; some of these may treat the wastes as well as store them). Since all contaminated liners will be removed or decontaminated at closure, it is environmentally acceptable for leachate to enter into such liners during the pile's or impoundment's active life. For example, suppose that a five-foot clay liner (but not the underlying soils) received some leachate during the active life, after which the entire contaminated liner system is removed. In that case, the standard of preventing migration out of the unit during its active life would have been met, and the environmental goal of long-term minimization of leachate migration would also have been achieved.

In accordance with the rationale explained above, the regulation requires that landfills, surface impoundments, and piles have liners designed to prevent migration to the adjacent subsurface soil or ground or surface water during their active lives. First, it further provides that in the case of a storage unit (i.e., a pile or a surface impoundment from which wastes and waste residues will be removed or decontaminated at closure), the liner may be constructed of materials that may allow wastes to migrate into the liner (but not into the adjacent subsurface soil or ground water or surface water) during the active life of the unit, provided that the liner is removed at closure. Thus, in appropriate situations, clay or admixed materials may be acceptable liner materials. Second, in the cases of landfills and of surface impoundments used to dispose of hazardous waste, the regulations provide that the liner must be constructed of materials that prevent wastes from passing into the liner. Synthetic liners are the only commonly-used materials of which EPA is aware that would meet this standard.

EPA recognizes that even a thin, 30-mil synthetic liner can sorb a *de minimis* quantity of wastes into its structure and allow some vapor to pass through. EPA of course, does not interpret such *de minimis* sorption or passage to violate the requirement that disposal units not allow wastes to pass into the liner. However, clay liners, even if relatively "tight," would violate this requirement.

It should be noted that the standard of designing to prevent migration is a design performance standard. It requires that liners be "designed constructed and installed" to prevent migration during the unit's active life. If the permittee complies with this requirement and the liner fails subsequent to installation despite such compliance, the permittee will not be in violation of the permit as it relates to this standard.

EPA is not requiring that liners prevent migration of wastes after the unit is closed rather, the regulations require that post-closure migration of liquids be "minimized". Absolute prevention of migration forever or for very long times is beyond the current technical state of the art. Thus, at some time some migration will probably occur. Thus, instead of relying on bottom liners to provide post-closure protection of ground water, EPA is relying principally on final cover (caps), as discussed below.

5. *Closure of Land Disposal Units.* A cap is a top liner, placed on the unit at closure. Caps, like bottom liners cannot be expected to last forever. However, a properly designed and maintained cap can prevent the entry of liquids into the closed unit, and thus the formation and migration of leachate, for many years and can minimize it thereafter in the absence of damage. Therefore, EPA requires that the cap be designed and constructed to provide long-term minimization of the movement of liquids into the closed unit. Because clays will generally last longer than synthetic materials, clay caps rather than synthetic caps should usually be the materials chosen to provide long-term minimization.

To avoid the build-up of liquids in the closed landfill or impoundment (the "bathtub effect") EPA requires that the cap be as impermeable as the bottom liner. This will require the installation of a synthetic membrane cap whenever the bottom liner is synthetic. Thus, many units will be required to have two-layer caps consisting of a synthetic layer to avoid the bathtub effect and provide short-term prevention of infiltration, and a clay layer to provide long-term minimization of precipitation infiltration and leachate generation. EPA believes that this will provide maximum short-term and long-term protection of human health and the environment.

EPA recognizes the need for certainty and uniformity in implementing the regulatory concept of "long-term minimization" of liquids migration.

Therefore, EPA is currently developing numerical limits for liquid migration. The technical approach being used is discussed in EPA's Guidance Document for Landfill Design—Liner Systems and Final Cover (see Section 9 of this preamble discussion below). EPA hopes to propose these numerical limits within six months.

6. *Existing Portions.* The design and operating standards contain a limited exemption for "existing portions" (defined today in § 260.10). An existing portion is any area on which waste has been or is being placed at the time of permit issuance. This may be one cell or trench of a landfill, an impoundment, or a section of a pile. Existing portions are exempt from the requirements to install liners and leachate collection systems. However, they remain subject to the remainder of the design and operating requirements (*e.g.*, placing a cover over wastes remaining at closure) as well as the ground-water protection requirements of Subpart F.

Installing liners and leachate collection systems at existing portions would create severe difficulties for many facilities. Owner or operators would have to remove wastes before installing liners and leachate collection systems. This presents several types of problems.

Some facilities may lack space in which to store the wastes temporarily while retrofitting. Even worse, in some cases, the ongoing waste disposal operation is integral to production operations. For example, some facilities use large volumes of water as part of their manufacturing processes and use surface impoundments to treat wastewater or to store or dispose of sludge. Unless additional space is available to construct a new impoundment to receive the wastes being removed from the existing impoundment, it may be impossible to retrofit the old impoundment without shutting down production facilities.

A second problem is safety. Exhuming wastes from a landfill, for example, may create significant hazards for workers and others who are nearby and may be exposed to the wastes.

The Congress recognized the problem of retrofitting existing units when it amended Section 3004 of RCRA in 1980 to add the following provision:

> In establishing such standards the Administrator shall, where appropriate, distinguish in such standards between requirements appropriate for new facilities and for facilities in existence on the date of promulgation of such regulations.

This provision does not absolutely require EPA to have separate standards for new and existing units but does indicate that EPA must consider whether distinctions should be drawn. The legislative history of this provision specifically indicates that the Congress was concerned about burdensome retrofitting problems that existing units might have in complying with location and design requirements that EPA might appropriately specify for new portions. H.R. Rep. No. 96–1444 (1980).

The limited exemption for existing portions in these rules implements the legislative intent. The exemption applies only to those requirements which would require dangerous or impracticable retrofitting at existing units (i.e., bottom liners and leachate collection and removal systems). Moreover, it applies only to existing portions of existing units. New portions of existing units (e.g., lateral extensions of existing landfills such as new cells or trenches) are not entitled to the exemption since they would not experience the retrofitting problems pertaining to existing portions.

EPA is concerned that this exemption may be too broad in some situations and too narrow in others. It may be that there are some situations where waste can be removed with minimal risk and at a reasonable cost even at existing portions, so that the policy concern behind the exemption is inapplicable. For example, it may be quite simple to remove a small waste pile or a small or partially filled landfill trench and place a liner underneath it. Similarly, it may be feasible to retrofit an existing surface impoundment that is used infrequently (e.g., to hold overflows) or that is not essential to daily production needs. Also, EPA realizes that there may be little environmental gain in requiring owners and operators of units very near the end of their operating life to comply with the liner requirements. For example, if 95 percent of the capacity of a landfill is consumed at the time of permitting, there may be little benefit to requiring a liner system under the remaining 5 percent. EPA does not currently have enough information to distinguish among various types and sizes of existing portions to fashion a narrower exemption. EPA requests public comment about the scope of the exemption and welcomes suggestions about how this exemption can be better crafted to address those situations where substantial retrofitting would not be necessary or could be accomplished without causing environmental harm or excessive burdens or, alternately, where upgrading practices at existing facilities may provide *de minimis* additional protection.

7. *Waiver from the Liner and the Leachate Collection and Removal Requirements.* If an owner or operator of an impoundment, pile, or landfill can demonstrate to the Regional Administrator that the use of alternate design and operating practices, in combination with location and waste characteristics, will prevent the migration of any hazardous constituents into the ground water or surface water forever, then he may obtain an exemption from the liner and the leachate collection and removal requirements. The basis for the exemption is that such requirements become superfluous if no potential threat to ground water or surface water will occur at any time.

An example of a situation for which this exemption may be appropriate is one where: (1) A large unsaturated zone below the unit is composed of materials that are capable of attenuating any hazardous constituents in the leachate before it reaches ground water or surface water (e.g., attenuating hazardous constituents through ion exchange); (2) the unit is located in an arid area in which precipitation does not recharge ground water; and (3) the unit handles only a small quantity of wastes. Given an appropriate combination of such factors, together with proper design and operating practices, (e.g., the use of a thick liner possessing substantial attenuative capacity), it may well be that the owner or operator could demonstrate that no hazardous constituents could ever migrate as far as the ground water or surface water.

Although the requirements for liners and leachate collection and removal systems apply only during the life of the unit, the waiver of these requirements is based on a demonstration that migration to ground or surface water will not occur at any future time. These requirements, while operative during the unit's active life, are designed to ensure that the post-closure migration of liquids is minimized to the extent that ground- or surface-water contamination will never occur. Therefore, a waiver of these requirements must logically be based on a showing that the equivalent environmental result will be achieved, i.e., that ground- or surface-water contamination will never occur.

EPA also considered granting a waiver from the closure provisions in situations as described above, where it is demonstrated that hazardous constituents cannot reach the ground water. However, the closure provisions have other benefits in addition to ground-water protection, including: (a) Prevention of the "bathtub" effect (i.e., filling with leachate and overflowing); (b) protection of surface water from run-off; and (c) discouragement of direct access to the wastes. The Agency has, therefore, decided not to waive the closure requirements where ground-water contamination is not possible.

Another waiver from the design and operating requirements considered by the Agency involved facilities located over aquifers which are not underground sources of drinking water (exempted aquifers under the Safe Drinking Water Act—see 40 CFR 122.35 and Section VII.D.5.c. of this preamble. The argument can be made that if an aquifer or a portion of an aquifer is, for some reason, not usable as a drinking water supply, then there is little reason to install devices (e.g., liners) to protect it. The Agency is concerned, however, that exempted aquifers or portions of aquifers under the Safe Drinking Water Act may be only temporarily exempted in some cases, and that they may flow into nonexempted portions, into surface water bodies, or into nonexempted interconnected aquifers (e.g., underlying aquifers). The Agency has not had time, however, to fully evaluate to what extent, if any, such an exemption may be protective and has, therefore, not included it in this promulgation. Existing facilities over exempted aquifers or exempted portions of aquifers will, however, be considered low priority for permitting pending review of this issue.

The Agency solicits comments on these and other waivers from the design and operating requirements which might provide adequate protection.

6. *Special Provisions for Double-lined Units: Exemption from the Ground Water Protection Requirements of Subpart F.* The design and operating standards contain special sets of standards for surface impoundments, piles, and landfills with double liners and leak detection systems. Compliance with these standards is not mandatory. However, if an owner or operator voluntarily applies for and is issued a permit to comply with these special standards (in addition to the other standards generally applicable to these units), then he is not subject to the ground water protection regulations contained in Subpart F (except under special circumstances discussed below).

These special standards require that there be two liners underlying the unit and a leak detection system between the two liners. The two liners must be designed and constructed in a manner that prevents the migration of liquids into or out of the space between the liners. This can be achieved by lapping or sealing the edges of two synthetic membrane liners at the surface. A leak detection system is any system (e.g., a drain and pump, or appropriate instrumentation) that enables the owner or operator to detect whether any liquid has entered into the space between the liners. If liquids are detected in the leak detection system, it may be concluded that the liquids resulted from a leak in one of the liners. Some water may enter the space between the liners at the time of installation. This would occur only once, at the time of unit start-up. A prudent owner or operator would remove this water at that time, since the presence of water in the leak detection system at a later time will be assumed to indicate that one of the liners is leaking.

If liquid leaks into the leak detection system, indicating a leak in at least one of the two liners, the owner or operator must notify the Regional Administrator within seven days after detecting the leak. He then has two options. One is to repair or replace the liner and obtain a certification from a qualified engineer that the leak has been stopped. This must be done within a period of time specified in the permit. The period of time should be set to ensure expeditious repair or replacement but, since one liner is still intact, can be set reasonably to cause minimal disruption of production processes that are dependent on the unit's continued operation.

For many units, repair or replacement is impractical, just as retrofitting an existing portion to install a liner is impractical, as discussed in the preceding section of this preamble. The second option is to forfeit the exemption from the Subpart F ground-water protection standards and to begin to comply with a detection monitoring program, under § 264.98, to ensure that any migration of leachate to ground water will be detected. However, this option is available only if such a program is already incorporated in the permit. Otherwise, after detection of the leak, ground-water contamination could ensue while proceedings are still being conducted to modify the permit to establish a detection monitoring program.

Ordinarily, a permit written for a double-lined unit seeking an exemption from Subpart F would not contain any detection monitoring requirements. In that case, if an owner or operator discovers a leak in the leak detection system, he will have to repair or replace the leaking liner or else be in violation of the permit. Therefore, EPA recommends that those who anticipate retrofitting problems in attempting to repair or replace leaking liners should request that detection monitoring programs be established in their permits in accordance with the requirements of § 264.98, as contingent requirements. Such requirements would be automatically triggered in the event of a leak, but would not have to be complied with until such a leak occurred. The permit would specify well placement, detection parameters to be monitored, and the frequency of monitoring. If a leak occurred, the permittee would then install the wells and begin monitoring in accordance with a schedule set forth in the permit.

The regulations require that the liners must meet the requirements normally applicable to liners in single liner systems: they must prevent the migration of wastes to subsurface soil or to ground water or surface water during the life of the unit. This is consistent with the policy objectives outlined in Sections VII.E.1. and VII.E.2. above. Furthermore, it should be noted that, as a practical matter, owners or operators seeking to use this exemption from Subpart F will insure that both liners prevent migration. Otherwise, leakage into the leak detection system will occur, resulting in the need to repair or replace the leaking liner or begin groundwater monitoring, as discussed above.

The leachate collection and removal requirements for single-lined piles and landfills also apply to double-lined systems. The leachate collection and removal system must be placed on top of the upper liner, and must be maintained and operated to collect and remove the leachate. This implements the policy objective of reducing the amount of leachate that can leach in the future to the subsurface soil or ground water or surface water.

Finally, to be eligible for the exemption from the Subpart F ground-water protection requirements, a double-lined unit (including the liners and leak detection system) must be placed entirely above the seasonal high water table. Placement of units in the ground water poses special problems associated, among other things, with external pressures applied by the saturated earth. The Agency is concerned that these pressures can cause disruption (collapse or caving in) of the liner system and disruption of the leak detection system to the point that it may not work. While collapse of the liner system can occur when a single liner unit is located in the ground water, the ground-water monitoring system can be expected to function to detect contamination. Since ground-water monitoring is waived for double-lined facilities, it is imperative that the leak detection system function. The Agency is not confident at this time that it can specify design safeguards that will ensure continued function when the unit is placed in the saturated zone (i.e., in the ground water).

9. *Specification of Design and Operating Requirements in Permits.* The design and operating standards in these rules are written as performance standards. The purpose in using the performance-standard approach is to address the legitimate concern of many commenters that the regulatory standards provide flexibility in meeting the performance goals established by EPA. This allows the use of cost-effective, site-specific designs, equipment, and operating practices, and encourages innovation.

In promulgating performance standards, EPA is relying on the issuance of permits to clearly establish the specific designs and operating requirements which each individual owner or operator must comply with. It is thus the permit-issuing authority's task to translate general standards into specific detailed obligations. The permit writer will do so in accordance with the procedural requirements of 40 CFR Part 124, which provide for the issuance of a draft permit, documentation explaining the basis for the conditions in the draft permit, a public comment period a public hearing if requested, the issuance of a final permit, and a right of administrative appeal.

The regulations for each type of land disposal unit contain a provision that requires that the Regional Administrator will specify in the permit all design and operating practices that are necessary to insure that the general design and operating standards are complied with. For example, the landfill standards require that leachate depth over the liner not exceed one foot. This requirement may be complied with by using a combination of design features (*e.g.*, slope and permeability of the drainage layer above the liner) and operating practices (*e.g.*, the amount of bulk liquids placed in the landfill) based upon assumptions concerning natural conditions (*e.g.*, expected precipitation rates). The permit writer will not only approve the design features but will also specify the operating practices in the permit. The documentation prepared to support the permit issuance (a statement of basis under § 124.7 or a fact sheet under § 124.8) would indicate the assumptions concerning natural conditions that were used in deriving appropriate design and operating conditions. Thus, the design features and operating practices incorporated in the permit will be those used by the owner or operator to demonstrate compliance with the performance standard (*i.e.*, the one-foot depth limit).

10. *Technical Resource Documents and Guidance.* EPA recognizes the need for guidance to assist applicants in understanding what specific designs and operating practices would be considered acceptable to EPA and to assist permit writers in establishing specific permit conditions. Accordingly, EPA has developed two groups of documents.

The first group is a series of eight detailed technical resource documents dealing with various technical issues. These documents discuss (a) facility design and operating technologies, and (b) methods for evaluating the performance of designs, but are not necessarily correlated with the regulations. These documents, in their current draft form (EPA expects to revise them by early 1983), are available from the National Technical Information Service, U.S. Department of Commerce, Springfield, Virginia 22161. The documents are as follows:

(1) Evaluating Cover Systems for Solid and Hazardous Waste (EPA Publication No. SW-867, NTIS Publication No. PB-81-166-340).

(2) Hydrologic Simulation on Solid Waste Disposal Sites (EPA Publication No. SW-868, NTIS Publication No. PB-81-166-332).

(3) Landfill and Surface Impoundment Performance Evaluation (EPA Publication No. SW-869, NTIS Publication No. PB-81-166-357).

(4) Lining of Waste Impoundment and Diposal Facilities (EPA Publication No. SW-870, NTIS Publication No. PB-81-166-365).

(5) Management of Hazardous Waste Leachate (EPA Publication No. SW-871, NTIS Publication No. PB-81-189-359).

(6) Guide to the Disposal of Chemically Stabilized and Solidified Waste (EPA Publication No. SW-872, NTIS Publication No. PB-81-181-505).

(7) Closure of Hazardous Waste Surface Impoundments (EPA Publication No. SW-873, NTIS Publication No. PB-81-166-894).

(8) Hazardous Waste Land Treatment (EPA Publication No. SW-874, NTIS Publication No. PB-81-182-107).

The second group is a set of four guidance documents correlating to the most important performance requirements (*e.g.*, liners and caps) contained in the design and operating standards promulgated today. These documents contain design specifications which the Agency believes will generally lead to compliance with the performance requirements. The purpose of these documents is to reduce the uncertainty associated with translating the general performance standards into specific and operating requirements for particular units. Thus, if an applicant follows one of the example specifications set forth in the guidance, he will generally receive a draft permit from EPA. (Of course, the final permit may contain different provisions from the draft permit, based upon an evaluation of comments received on the draft permit.)

At present, the draft guidance documents contain only a few design examples. The examples will be expanded over time as EPA gains experience implementing the regulations. The current drafts are available at U.S. Environmental Protection Agency, Central Library, Room 2404, 401 M Street, S.W., Washington, D.C. 20460 and in EPA's Regional office libraries. The documents are:

(1) Surface Impoundments—Liner Systems, Final Cover, and Freeboard Control;

(2) Waste Pile Design—Liner Systems;

(3) Land Treatment Units;

(4) Landfill Design—Liner Systems and Final Cover. These documents will soon be available from the National Technical Information Service. EPA will announce their availability in the **Federal Register.**